Report of the DRAKKAR Workshop
Grenoble, 21-23 january 2019

Link to the workshop website

Organizing committee
Bernard Barnier (CNRS, IGE), Arne Biastoch (GEOMAR), Claus Böning (GEOMAR), Julie Deshayes (CNRS, LOCEAN), Joël Hirschi (NOCS), Camille Lique (IFREMER, LOPS), Adrian New (NOCS), Anne Marie Treguier (CNRS, LOPS).

The agenda was organized in three oral sessions and a poster session.

1. Benefits, challenges and future needs regarding basin-scale ocean simulations at 1/20°-1/60° resolution
2. Improving ocean models for climate and operational applications.
3. Understanding ocean-ice-atmosphere interactions and their consequences for ocean modelling strategies.

The poster session, organized for the first time at a DRAKKAR meeting, included a focus on "Atmospherically forced vs intrinsic ocean variability, uncertainties and ensemble strategies". The poster session has been appreciated, but participants have expressed a preference to have the poster session in the middle of the meeting and not at the end next year.

The meeting was held back-to-back with the kick-off meeting of the H2020 IMMERSE project, Improving Models for Marine EnviRonment SErvices. This project, led by J Le Sommer, IGE, will support developments of NEMO during the period 2018-2022.

The list of participants is included in this report (annex 1) as well as the list of abstracts (annex 2). Presentations are available on the meeting web site (password-protected).

1. Sessions highlights

1.1. Benefits, challenges and future needs regarding basin-scale ocean simulations at 1/20°-1/60° resolution

In this session three groups presented results of basin-scale simulations at 1/60° using NEMO.
- At GEOMAR the strategy is to use AGRIF zooms to embed a domain at 1/60° into a 1/12° zoom of ORCA025 (two levels of zoom). The focus is the Agulhas region, gateway between the Indian and Atlantic Ocean. The INALT family is a consistent set of nested 1/10° to 1/60° resolution configurations (Schwarzkopf et al, submitted to GMD). Energy transfers in the sub-mesoscale regime have been investigated by R. Schubert (publication to be submitted to Ocean Modelling).
- At IGE, a regional configuration of the North Atlantic at 1/60° and 300 vertical levels has been developed and is now being run with tidal forcing (Le Sommer and Brodeau). A spectral analysis of the energy cascades and mesoscale inertial range has been performed by Ayaji, who compared NATL60 and a Hycom simulation at 1/50°.

- At the University of Alberta, a configuration based on the 1/4° north Atlantic with two levels of zoom (1/12° and 1/60°) has been developed to focus on the Labrador Sea. Results are still preliminary (Pennely et al).

Such high resolution simulations generate a large amount of data and we must look for new analysis tools. Ryan Abernathey (LDEO, U.S.A.) was invited to present the platform PANGEO and the potential of data science techniques and parallel computing in the cloud.

1.2. Improving ocean models for climate and operational applications.

Different modelling strategies has been presented at this Drakkar meeting (FESOM model at AWI and Australian consortium COSIMA). We summarize here only the main developments based on NEMO:
- vertical coordinates: first successful test of z-tilde in ORCA025 by A. Megann (NOCS).
- vertical coordinates: use of z-sigma coordinates at 1/4° and 1/12° resolutions to improve overflows (P Mathiot, MetOffice, in collaboration with IGE).
- coupling with sea ice and the WW3 model in the Arctic at 1/4° resolution (G. Boutin)
- coupling NEMO with the new neXt-SIM ice model (E. Olason, NERSC).
- improvements to the NEMO iceberg module for the CREG Atlantic-Arctic configuration (J. Marson, University of Alberta).
- coupling of a NEMO-AGRIF configuration with the atmospheric model ECHAM6 (J. Harlaß, GEOMAR)

1.3. Understanding ocean-ice-atmosphere interactions and their consequences for ocean modelling strategies.

This session started with an invited talk by L. Renault (LEGOS). Based on an extensive set of coupled models, the ocean current feedback on the wind stress is now well understood and quantified. L Renault proposed an optimal way to force an ocean model, taking the feed-back into account.

Results of the ALBATROSS project (Copernicus-CMEMS) have been presented by F. Lemarie and X Couvelard (WW3-NEMO coupling at the global scale and development of a simplified atmospheric boundary layer as an improved method to force NEMO). G. Samson evaluated sensitivity to the choice of bulk formulae in e-ORCA025 (poste).

The coupled ocean-atmosphere high resolution global simulations of the MetOffice (with ORCA12 and ORCA025) have been used to examine the effect of eddies on coupling at the mesoscale (Ashby et al, submitted to Ocean Modelling).

A comparison of three forcing sets (CORE, DFS and the Japanese reanalysis JRA55) has been performed using ORCA025 (A. Megann, NOCS). A comparison between CORE and JRA55 has also been done at GEOMAR (P. Wagner), and JRA55 has been used to force a global configu-ration at CMCC (poster by D. Iovino).

Operational developments at ECMWF have been presented: use of ORCA025 coupled for op-erational forecasts (K. Morgensten) and the new reanalysis ERA5 (N. Wedi).

In the second part of the session, new results were presented regarding the circulation in the subpolar Atlantic and the Arctic based on the analysis of global or regional configurations (presentations by P. Myers, C. Talandier, H. Regan, Y Aksenov). Finally, Adam Blaker (NOCS) showed puzzling preliminary results, regarding the MOC high frequency variability near the equator.

1.4. Atmospherically-forced vs intrinsic ocean variability, uncertainties and ensemble strategies.

This thematic session gathered 4 posters, mostly based on the analysis of the OCCIPUT 50-member global ensemble simulation.

Comparing the ensemble mean and ensemble spread of regional sea level trends over 1993-2015, W. Llovel showed that these trends cannot be unambiguously attributed to atmospheric influences (natural and anthropogenic) over 38% of the global ocean area (47% over 2005-2015).

Starting from an analysis of the spatiotemporal scales of forced and intrinsic and SLA variability at global scale, S. Close proposed a method to strongly attenuate the signature of the latter in observed SLA fields; this allows for instance to unveil the direct response of the real ocean to the NAO in several regions of the North Atlantic.

Focusing on the Gulf of Mexico and surrounding regions, I. Garcia-Gomez presented new metrics (instantaneous entropy, probabilistic coherence/phase analyses) for the analysis of ensemble simulations with strongly non-Gaussian or bimodal ensemble PDFs: they allow to discriminate regions where the atmospheric variability actively restrains the ocean's chaotic variability at certain timescales (e.g. hurricanes inducing strom surges around the Gulf rim in all members) and those where it barely manages to do so (Gulf Stream, Loop Current), and to highlight the periods (10-11 months) where intrinsic variability makes the Loop Current and deep Yucatan channel transport covary with a 1-month lag.

From a very large ensemble of idealized simulations, S. Pierini introduced the concept of Global PullBack Attractor to disentangle the ocean intrinsic variability from its atmospheric modulation, consistently with dynamical systems theories. This poster showed that a time-varying ensemble mean is not the best description of the "forced" variability.

2. Progress on the DRAKKAR IRN axes, and discussions

The discussions contribute to the strategy of the Drakkar International Network, 2018-2021.

2.1. DRAKKAR IRN axis 1: coordinating simulations and developments

“Lead the development of a coherent hierarchy of global model configurations based on the NEMO modelling framework, and in particular the development and improvement of the global 1/4° ORCA025 model and the 1/12° ORCA12 model. “

2.1.1. Discussion about sharing configurations

A discussion has been led by Julie Deshayes (LOCEAN) and Marcus Scheinert (GEOMAR) to address the questions: How to share configurations with NEMO? Could the Drakkar community better share experience with NEMO and how could the Drakkar community contribute better to the development of NEMO ?

Markus Scheinert presents the challenge of sharing configurations and possible solutions. Sharing configurations is necessary for reproducibility, comparability, trackability of the science. The difficulties come from different groups having different practice, the rapid evolution of machines, compilers, libraries, the complexity and volume of input and output files.

A configuration is a set of default settings for a simulation. It is a collection of files. It includes modified source files, compiler settings, CPP keys. It also includes default options of a namelist and one set of input files. It should include also an example of output and evaluation routines. There are four options for sharing: 1) complete duplication of the code, multiple NEMO repositories ; 2) direct exchange of bundle of files (tarballs) between users; 3) a git repository for each configuration, linked/synchronized with a version of NEMO; 4) use of the "unsupported configuration" option of the NEMO server (makenemo -u). The solution 3) is preferred because it avoids duplication or risk of data loss and it allows a version control of each configuration, which is not possible in (4). The development of this solution is proposed as part of the European project IMMERSE (Work Package 2, task 2.3).

Julie Deshayes presents the survey that has been done in the DRAKKAR community (19 answers). First question concerned the type of information that could/should be shared. A general consensus lists configuration details, model enhancements, namelists, boundary conditions and all input files as items to be shared but discussion highlights the need to share the tools that lead to the input files. Also tools are easier to share. A clear protocol for sharing configurations (including all informations that contribute to defining a configuration) seems to be a key start to developing greater community. Alistair Adcroft explains that orchestration of the community around MOM6 is different, but still the exchange of configuration is important. They are using git only for these excahnges, ecept for big binary files ; they also share tools used to compute input files for the configurations. Jean-Marc Molines points toward the NEMO special issue in GMD publications as a way to share knowledge about configurations. Sharing of datasets and notebooks is a way to ensure reproducibility of model analyses, as required for scientific publishing.

Then the survey questioned about interactions between DRAKKAR and NEMO development. It seems that DRAKKAR collaborators find it hard to link back to NEMO consortium and system team, hard to know how best to interact and share knowledge. On the other hand, NEMO system team acknowledges that it is hard to follow what is happening outside the development of NEMO, and would benefit from more communication with NEMO users : could that be the role of DRAKKAR ? Ways to share model development are reminded : tickets and forums for NEMO developments, while sharing configuration should remain outside. It is also reminded that anything new has to go through NEMO system team for review. It is suggested that DRAKKAR collaborators take part in NEMO working groups, which are open, for example the AGRIF working group could grow with contributions from Germans and

Canadians. The list of working groups, coordinators, activities and minutes of meetings are found on the forge:
http://forge.ipsl.jussieu.fr/nemo/wiki/WorkingGroups
A suggestion is made to have more tightly focused working groups that could motivate users more.

Finally, the purpose of DRAKKAR and long-term motivation of the group is discussed. A newsletter could be a way to facilitate communication between groups in different geographical regions. A protocol to inform others about what we are all doing, could favor coordination in the development of new configurations, and that could be particularly relevant for the 1/60 degree experiments. In the end, DRAKKAR tries to bring groups together who are doing their own science, but still are linked to each other in their use of NEMO and their scientific questions. It is reckoned that although sharing within the group is relatively smooth, coordinating is much more difficult. Yet Drakkar is like putting oil in the system, making science work and questions go faster. A session for planned experiments, work in progress and pending questions, could avoid duplicating efforts – maybe that could be scheduled every few years during DRAKKAR workshops. Another important point is to keep memory of topics discussed in past Drakkar meetings. Markus Scheinert suggests that a DRAKKAR git group could improve communication, and volunteers to set it up.

2.1.2. Other points relevant for IRN axis 1

In previous DRAKKAR meetings, the main participating groups presented their strategy. It is no longer the case because this led to a very long session that was too repetitive from one year to the next. However, some participants feel there is a need to share future plans. One suggestion would be to have such a session once every few years, or else, to find a way to present strategic plans more concisely.

An action item was decided for 2018 but was not carried out (make monitoring output for these simulations easily available and inter-compare key variables). Anne Marie, Thierry and Bernard will reconsider the utility/possibility of this action.

2.2. DRAKKAR IRN axis 2: uncertainties

“Quantify the uncertainties in global numerical solutions of high resolution ocean models and their propagation. “

Developments regarding this axis have been presented in the poster session; no specific discussion has been organized this year.

2.3. DRAKKAR IRN axis 3: towards higher resolution

“Develop and generalize the use of grid-refinement strategies (e.g. AGRIF) to study fine scale key ocean processes in their realistic global environment (downscaling) and to understand their role in the large scale circulation (up-scaling). This work will benefit from high resolution basin-scale frontier simulations.”

The high resolution simulations and AGRIF strategies have been a strong focus of this DRAK-KAR meeting, following last year's decision. This focus included oral session 1 as well as a discussion : "The need to go to ultra-high (1/60° and below) resolutions. What do we gain? What is required in terms of additional processes (e.g. tides)?" which is summarized below.

Objectives of high (1/60°) resolution simulations:

- Mesoscale resolving at high-latitudes
- Going towards the coasts, regionalization (e.g. South Africa)
- Submeso-mesoscale coupling, mesoscale dissipation
- Internal gravity waves and tides, impact of small scale topography
- Preparing satellite observation missions
- Exchanges between the ocean and the shelf, the upper and subsurface ocean
- design parameterizations for lower resolution models

Discussion items:

Is 1/60° an interesting regime ? It depends on regions and dynamical regime. Issue of numerical convergence : is numerical convergence possible ? Not in an absolute sense: the more you crank up resolution the more you see new processes emerge. Perhaps we should focus on numerical convergence for the mesoscale range. Remember that resolved scales are 5-10 times the grid size. Some participants note that choosing a specific resolution is not always a scientific choice. Available computing resources are a strong constrain.

What vertical resolution, coordinates, bottom boundary layer at these resolutions? There is a diversity of choice among the 1/60° configurations presented: the Labrador Sea Canadian configuration has 75 levels, the GEOMAR Agulhas configuration has 120 levels, the IGE NATL60 has 300 levels. Stewart et al (Ocean modelling, 2017) have proposed a method to construct vertical grids objectively in order to resolve the vertical structure of the baroclinic modes allowed by the horizontal grid. At /12° ORCA12 aims to resolve the second mode, 75 levels are O.K.. But we also run ORCA1 (1°) with 75 levels. At IGE, with 300 levels we to get good overflows, with a resolution of the Ekman layer. What about 1/36° ? What vertical resolution is best at that resolution?

Benefits of collaborations to explore this new frontier are emphasized: the comparison between NATL60 and HYCOM 1/50° is an example. We have a lot to grain by collaborating on the technical challenges.

These simulations produce very large datasets. How can we analyze them? The tools developed by R. Abernathey (PANGEO) are designed for these high resolution outputs. There is a PANGEO group in France.

How can we assess these very high resolution simulations against (rare) observations ?
Are mentioned: OSMOSIS, SST, sea color, along-track altimeters, currentmeters, HF radars near the coasts, gliders, take better advantage of Argo, SAR satellite. There is no high resolution dataset in the deep ocean, but we must look at very high resolution runs with existing

(medium-resolution) data, while developing methods to consider local/profile/instantaneous data + statistics (break away from climatologies & gridded datasets).

Other discussion items were: do we need to simulate internal tides? How accurate/Ready are our models to go to these simulations (at 1km resolution the hydrostatic approximation is fine, but do we need new numerical developments?)

2.4. DRAKKAR IRN axis 4: improved the representation of surface air-sea-ice interactions

Ongoing projects contributing to this axis have been presented in oral session 1.3. The DRAKKAR community will implement and test the method proposed by L. Renault to forced ocean models. A collaboration between ECMWF, IGE and other groups will be initiated to discuss the potential of new reanalyses to force ocean models.

ANNEX 1: List of participants

Registered Participants (85)

IGE - Grenoble (11): Bernard Barnier, Thierry Penduff, Sally Close, Julien Le Sommer, Jean Marc Molines, Ixelt Garcia-Gomez, Aurélie Albert, Adekunle Ajayi, Nicolas Jourdain, Redouane Lguensat
GEOMAR - Kiel (10): Arne Biastoch, Klaus Getzlaff, Joakin Kjellsson, Patrick Wagner, Jan Harlaß, Markus Scheinert, Jan Klauss Rieck, Franziska Schwarzkopf, Willi Rath, Claus Böning
NOC - Southampton (8): Adrian New, Alex Megann, Adam Blaker, Yevgeny Aksenov, Stephanie Rynders, Andrew Coward, James Harle, Simon Müeller
LOPS - Brest (6): Anne-Marie Treguier, Claude Talandier, Camille Lique, Guillaume Boutin, Heather Regan, Xavier Couvelard
LOCEAN - Paris (6): Gurvan Madec, Julie Deshayes, Anne Cécile Blaizot, Sebastien Masson, Claire Levy, Sybille Techene
Met Office Hadley Center - Exeter: (4): Pierre Mathiot, Dave Storkey, Mike Bell, Sophia Ashby
IORAS Moscow (4): Sergey Gulev, Polina Verezemskaya, Margarita Markina, Roman Sedakov
University of Alberta - Edmonton (3): Paul Myers, Clark Pennely, Juliana Marson
AWI Bremerhaven (3): Sergey Danilov, Dmitri Sidorenko, Nicolay Koldunov
MERCATOR Ocean Intl - Toulouse (3): Guillaume Samson, Jérôme Chanut, Yann Drillet
LEGOS - Toulouse (3): Lionel Renault, Julien Jouanno, William Llovel
ECMWF - Reading (2) : Christian Mogensen, Nils Wedi
LJK - Grenoble (2): Laurent Debreu, Florian Lemarié
Nansen Center - Bergen (2): Pierre Rampal, Einar Olason
Ocean Next - Grenoble (2): Laurent Brodeau, Stéphanie Leroux
UCL - Louvain la Neuve (2): Pierre-Vincent Huot, Charles Pelletier
Università di Napoli Parthenope (1): Stephano Pierini
Università di Venezia (1): Guisy Fedele
LSCE - Orsay (1): James Orr
NOC - Liverpool (1): Maria Luneva
University of Reading (1): Rémi Tailleux
Florida State University (1): William Dewar
Columbia University - Palissades (1): Ryan Abernathey
University of New South Wales - Sydney (1): Guillaume Serazin
Australian National University - Canberra (1): Andy Hogg
Institut for Coastal Reasearch - HZG, Geesthacht (1): Joanna Staneva
Princeton University (1): Alistair Adcroft
British Antarctic Survey, Cambridge (1): Christopher Bull
CMMC - Bologna (1): Dorotea Iovino
LEMAR - Brest (1): Laurent Memery

ANNEX 2: list of abstracts

Session 1
Benefits, challenges and future needs regarding basin-scale ocean simulations at 1/20-1/60° resolution

1. The INALT family - a set of high-resolution nests for the Agulhas Current system within global NEMO 3.6 ocean/sea-ice configurations

Franziska Schwarzkopf, Arne Biastoch
GEOMAR, Kiel

The greater Agulhas Current system plays an important role in the connectivity between the Indian and Atlantic oceans. It is highly dominated by mesoscale dynamics. To investigate their influence onto the regional and global circulation, a family of high-resolution ocean general circulation model configurations based on NEMO 3.6 has been developed. High resolution is achieved by embedding two-way AGRIF-nests covering the South Atlantic and the western Indian Ocean at 1/10° (INALT10) and 1/20° (INALT20) resolution in global ORCA05 and ORCA025 configurations, respectively. A secondary nest at 1/60° resolution (INALT60) has been developed to gain insights into the sub-mesoscale processes in the AC system.
Large-scale features such as the Drake Passage transport and the strength of the Atlantic meridional overturning circulation turn out to be rather robust among the different configurations documenting the important role of the host configurations to provide a consistent embedding of the regional grids into the global wind-driven and overturning circulations.
The dynamics of the AC system strongly depend on the representation of mesoscale processes. Both, the southward flowing AC and the northward flowing Agulhas Undercurrent increase in strength with increasing resolution towards more realistic values, documenting the importance of improving mesoscale dynamics as well as bathymetric slopes along this narrow western boundary current regime. The exploration of numerical choices such as sidewall boundary conditions and details of the wind stress calculation demonstrates the range of solutions within any given configuration.

2. Submesoscale Impacts on Mesoscale Agulhas Dynamics

René Schubert, Franziska U. Schwarzkopf, Willi Rath and Arne Biastoch
GEOMAR Helmholtz-Centre for Ocean Research, Kiel. Contact: rschubert@geomar.de

Mesoscale dynamics in the Agulhas current system determine the exchange between the Indian and Atlantic oceans, and thus the global overturning circulation. Here we present a series of JRA55-do forced, global NEMO configurations with horizontal grid refinements for the greater Agulhas region and show that the simulation of the Agulhas mesoscales and in particular the Agulhas rings improve, the more submesoscale features are permitted by the model configurations. We start with a horizontal grid refinement of 1/20° (~4.5 km), 46 vertical levels and a horizontal model diffusion contributed from TVD and EEN advection schemes and explicit diffusion. Subsequently we gradually increase the vertical level number to 120, change the diffusion setup to only numerical diffusion by UBS advection schemes and finally insert a second nest with a horizontal resolution of 1/60° (~1.5 km) that covers the Agulhas current system from 25°S - 45°S and from 0°E - 40°E.

The usual validation of ocean models against observed vertical sections and gridded products of sea surface height (SSH) is covering only the large-scale circulation and the integrated eddy activity. Therefore, we extend the validation by a scale-dependent comparison of the time-mean horizontal wavenumber spectra of sea surface temperature (SST), SSH and surface kinetic energy (SKE) from the models with the one from satellite data (MODIS SST, JASON-2 SSH) and predictions by theory (SSH and SKE). The spectral validation shows for the 1/60° model very good agreement in the Agulhas ring path on all comparable spatial scales down to 10 km. Turbulence in the 1/20° models is found to be associated with too steep inertial range slopes and with too low mesoscale power levels for sea surface height – in particular in the Agulhas ring path. A change from 46 to 120 vertical levels is found to be not associated with a significant change in the spectra. The discrepancy gets smaller when additionally the model diffusion is reduced and some submesoscale features are permitted in the 1/20° model.
The reason for the improvement is hypothized to be the upscale energy transfer associated with the more and more permitted submesoscales. Surface scale energy transfers derived with the coarse graining approach of Aluie et al. (2018) show for the 1/60° model that in the Agulhas ring path energy is transferred upscale at scales down to 10 km. In the greater Agulhas region at the surface, this energy cascades upscale and leads to a 25 % increase in energy transfer into mesoscales larger than 100 km in the 1/60° model compared to the 1/20° model without submesoscale activity. In the Agulhas ring path, where the model improves most, this energy transfer is found to be even five times larger. The computationally expensive calculation of scale energy transfer was performed in parallel using the Python-based toolboxes xarray/Dask on the Kiel-University Linux cluster.

3. Assesment of resolved fine scale surface fields in the (non-tidal) NATL60 model configuration.

Julien Le Sommer, Jean-Marc Molines, Aurélie Albert, Laurent Brodeau, Adekunle Ajayi, Guillaume Serazin (2), Thierry Penduff, Bernard Barnier.
IGE, Grenoble, (2) NSW University, Sydney
This presentation will focus the assessment of the first generation North Atlantic 1/60° NEMO model configuration set up in preparation for the upcoming Surface Water and Ocean Topography (SWOT) satellite altimetry mission. This model configuration, named NATL60, is aiming at providing virtual realisations of sea surface fields in order to prepare inversion and reconstruction algorithms for SWOT ocean data. NATL60 covers the North Atlantic Ocean from 25°N and 66°N with a horizontal resolution ranging from 1.6 km at the southern most latitude to 0.9 km nearby the northern boundary. The vertical grid uses 300 levels. Results from 18-month non-assimilative run, without tidal forcing, will be presented showing how NATL60 resolves ocean surface properties down to 15km scale.
Comparison with observation will be presented showing that how the model represents the mean circulation features and hydrography of the North Atlantic Ocean. Comparisons with conventional nadir altimeters (Saral and Sentinel 3-A) will show that NATL60 model is able to reproduce the variance levels and spectral slopes of sea surface height over the range of observed scales of motions (>70km). Comparisons with OSMOSIS currentmeter array will show how the model reproduces the statistics of gradients of ocean surface currents down to 15km scale. We will also present an assessment of resolved lateral temperature, salinity and buoyancy gradients with respect to a new compilation of TSG data.

4. Regimes of inverse energy cascade in ocean mesoscale inertial range

Adekunle Ajayi (1), Julien Le Sommer (1), Eric Chassignet (2), Jean-Marc Molines (1), Xiaobiao Xu (2), Aurélier Albert (1)
(1) IGE, Grenoble, (2) COAPS, FSU, Tallahassee.
Kinetic energy wavenumber spectra provide information on the regime of turbulent energy exchanges across scales in the ocean. This is why a lot of efforts have focused on assessing how the slopes of ocean surface kinetic energy wavenumber spectra compare with the slopes predicted by simplified models of ocean dynamics (QG, SQG) in the quasi-two dimensional turbulence inertial range. Analyses of high-resolution ocean circulation models suggest that the slopes of ocean surface kinetic energy wavenumber spectra lie between the prediction of QG (k^{-3}) and SQG (k^{-2}) models with strong spatial variations modulated by the levels of surface eddy kinetic energy. Analysis from altimetry also show contrasted results, within the limits set by the resolution capability of current generation altimeters. In this study we focus on quantifying the rate of turbulent kinetic energy exchange and the inverse cascade of energy through advective nonlinearity in the mesoscale inertial range. Our analysis is based on model output from two kilometric grid resolution, North Atlantic, sub-mesoscale permitting ocean circulation model configurations based on HYCOM and NEMO respectively. The two models are shown to compare favourably with observations at scales larger than their effective resolution (~10-15km). The novelty of this study is to focus specifically on kinetic energy exchanges within the inertial range, which is defined as the scales between the dominant energy containing scale (integral scale) and the models effective resolution (where numerical dissipation becomes significant). Our results show that north of 30°N the energy containing scale of mesoscale eddies decreases with latitude following the first Rossby radius of deformation (Rd) while the nonlinearity of eddies (ratio of the Rhine scale Rh to integral scale) increases with latitude. Within the inertial range, we find that surface kinetic energy wavenumber spectra show slopes close to k^{-3}. Model turbulent regimes are therefore comparable with QG predictions in most of the North Atlantic Ocean north of 30°N, in both high and low eddy kinetic energy regions. Analysis of KE transfers due to advective nonlinearity further show that, in most of the North Atlantic, KE is injected at scales close to Rd and cascades towards larger scales. In regions of weak non-linearity this inverse cascade is arrested close to the Rhine scales (Rh). Our result also show that estimates of KE transfers based on geostrophic currents significantly underestimate the inverse cascade, which questions our ability to infer oceanic energy cascade from altimetry and the future SWOT mission.

5. Inclusion of realistic tidal motions in submesoscale-permitting simulations of the North Atlantic with NEMO – eNATL60

Laurent Brodeau (1), Julien Le Sommer (2), Jean-Marc Molines (1), Jacques Verron (1,2), Aurélie Albert (2), Brian Arbic (3), Adekunle Ajayi (2), Jérôme Chanut (4), Florent Lyard (5), Aurélien Ponte (6), bernard Barnier (2), Thierry penduff (2), Pierre Brasseur (2)
(1) Ocean Next, grenoble, (2) IGE, Grenoble, (3) University of Michigan, (4) Mercator Ocean International, Toulouse, (5) LEGOS, Toulouse, (6) IFREMER, Brest. Contact: laurent.brodeau@ocean-next.fr
Basin to global submesoscale-permitting simulations of the ocean circulation down to the kilometric grid scale has recently been made technically achievable thanks to the continuous increase in performance capabilities of supercomputers. Data from this type of simulations, provided they realistically represent oceanic motions at fine scale, can be used for preparing

satellite observation missions and for guiding the design of the next generation operational systems. Yet, due to the computational costs of these simulations, it remains highly challenging to perform sensitivity experiments/analysis. Moreover, the relative scarcity of observational data available at scales ~10 km makes it also challenging to assess how realistic these simulations are.

The ability of these submesoscale permitting models to realistically simulate tides and internal tides remains to be addressed. In particular, there is a need to document the impact of including tidal forcing in these models, and to understand more precisely how tidal motions affects both large and fine scale flow properties.

Here, we report on the design, the status, and the first diagnostics of our ongoing multiyear-long sensitivity twin experiment performed with a basin-scale model at kilometric resolution: a simulation is performed with tidal motion and the other without. One of the main scientific purpose of this twin experiment, which has mainly been designed in preparation for the upcoming SWOT satellite altimetry mission, is to assess the impact of the explicit representation of tides. Our model, eNATL60, is a basin-scale configuration of NEMO (Nucleus for European Modeling of the Ocean) that spans

the North Atlantic from about 6°N up to the polar circle, and fully includes the Gulf of Mexico, the Mediterranean Sea, and the Black Sea. The horizontal grid resolution is about 1/60° while the vertical dimension is discretized along 300 levels, for a complete computational domain of 10 billion points.

6. The Western Boundary Current systems of the Atlantic at the surface and at depth within VIKING20X: Representation, connectivity and variability

Klaus Getzlaff, Arne Biastoch, Claus Böning
GEOMAR, Kiel.

7. Sub-mesoscale modelling of the Labrador Sea.

Clark Pennely and Paul Myers
University of Alberta, Edmonton

The Labrador Sea is a very dynamic region, with physical processes occurring at a variety of scales, from large scale gyre circulation to small scale convection processes. These small scale features are difficult to represent with numerical simulations due to high computational costs. We carry out a NEMO simulation incorporating two AGRIF nests to achieve 1/60° horizontal resolution (about 900m) in the Labrador Sea. We apply high spatial (about 30km) and temporal (hourly) atmospheric forcing from the Global Deterministic Prediction System produced by the Canadian Meteorological Centre.

This expensive simulation has completed four winter periods so far, though about 10 years remain to be simulated. We will showcase some results, primarily focused on the greatly improved spatial extent of convection, subduction of Labrador Sea Water, and resolved eddies including Irminger Rings. Four passive tracers have been included and will be discussed: Greenland runoff, Canadian Arctic outflow, Labrador Sea Water produced during convection, and Irminger Water which flows west past Cape Farewell. Furthermore, we will illustrate some of the challenges setting up such a simulation.

8. The Nature of Eddy Kinetic Energy in the Labrador Sea: Different Types of Mesoscale Eddies, their Temporal Variability and Impact on Deep Convection

Jan Klaus Rieck, Claus W. Böning, and Klaus Getzlaff
GEOMAR, Kiel.

This study investigates the different sources and impacts of Eddy Kinetic Energy (EKE) and its temporal variability in the Labrador Sea (LS) with the help of two hindcast simulations of an ocean model with 1/20 degree resolution in the North Atlantic (VIKING20X). Results from a simulation forced with the well-established CORE.v2 (Large and Yeager, 2009) atmospheric forcing are supported by results from a simulation with the new JRA55-do (Tsujino et al., 2018) product. The realistic forcing and geometry together with the high resolution of VIKING20X are crucial to the correct simulation of the three types of eddies in the LS. The anticyclonic Irminger Rings from the West Greenland Current affect the preconditioning of the northern central LS and their temporal variability is linked to the large scale circulation of the subpolar gyre. The main source of EKE and restratification in the central LS are Convective Eddies (CE) generated by baroclinic instabilities near the bottom of the mixed layer during and after convection. The temporal variations of CE are associated with local air-sea heat fluxes. The Boundary Current Eddies shed from the Labrador Current appear to exert only minor influence on preconditioning and restratification.

9. Sensitivity of an idealized storm track to current-topography interactions

Julien Jouanno and Xavier Capet
LEGOS, Toulouse. Contact jouanno@legos.obs-mip.fr

The dynamical balances of the Antarctic circumpolar current and their implications on the functioning of the world ocean are not fully understood and poorly represented in global circulation models. In this study, the sensitivities of an idealized Southern Ocean (SO) storm track are explored with a set of eddy-rich numerical simulations. The classical partition between barotropic and baroclinic modes is sensitive to current- topography interactions in the mesoscale range 10-100 km, as comparisons between simulations with rough or smooth bathymetry reveal. Configurations with a rough bottom have weak barotropic motions, no wind-driven gyre in the lee of topographic ridges, less efficient baroclinic turbulence, and thus larger circumpolar transport rates. The difference in circumpolar transport depends on the strength with which (external) thermohaline forcings by the rest of the world ocean constraint the stratification at the northern edge of the SO. The study highlights the need for a comprehensive and scale-dependent treatment of the ACC interactions with the ocean floor. It also sheds some light on the behavior of idealized storm tracks recently modelled: i) the saturation mechanism, whereby the circumpolar transport does not depend on wind intensity, is a robust and generic attribute of ACC-like circumpolar flows ii) the adjustment toward saturation can take place over widely different time scales (from months to years) depending on the possibility (or not) for barotropic Rossby waves to propagate signals of wind change and accelerate/decelerate SO wind-driven gyres. The real SO with a typical ACC saturation time scale of 2-3 years seems to lie in the “rough bottom/no wind-driven gyre” regime.

10. Fine-resolution simulations with FESOM

Nicolay Koldunov, Dmitri Sidorenko, Sergey Danilov.
AWI, Bremerhaven

Variable resolution proposed by unstructured meshes is well suited to simulate locally eddy resolving flows. We briefly review our previous efforts with FESOM on resolving local ocean dynamics and on selection of optimal mesh resolution. Much larger setups have become possible at present by switching to finite-volume dynamical core. Our current work (in progress) is with a 1 km Arctic setup, where the entire Arctic basin is at uniform resolution of 1 km, and resolution is gradually coarsened to 30 km in the rest of the ocean. FESOM throughput on this mesh (11.6M surface vertices) is ~1 SYPD on 5000 cores, or faster if computational resources are available. The simulated distribution and production of eddy kinetic energy is very non-uniform in the Arctic Ocean, and the simulated eddies are relatively weak in the deep basins, where the first Rossby radius is between 5-11 km, i.e., well resolved. However, the eddies observed in the Canadian basin are just about this size, and even higher resolution than 1 km might be needed to simulate them properly. We focus our research on the role of eddies in maintaining freshwater balance in the Beaufort Gyre.

11. How to retool a group of NEMO users

Willi Rath, Jan Klaus Rieck, Markus Scheinert, René Schubert, Patrick Wagner, Martin Claus, Swantje Bastin, Arne Biastoch, Sebastian Wahl

GEOMAR Helmholtz Centre for Ocean Research, Kiel. Contact: wrath@geomar.de

The first part of this talk summarizes lessons learned from successful efforts to shift scientists at GEOMAR to modern analytics tools (many of them from the Scientific Python stack), to the adaptation of best practices in software development for scientific software, and to the use of massively parallel compute resources for interactive and non-interactive analyses. While progress was made in small increments and along convoluted paths, there is a common pattern to most of the achievements. The obstacles we faced while establishing new approaches all traced back to the scarcity of time that constrains many scientist's decisions and hence makes it difficult for them to freely explore new techniques. Key ingredients to overcome these obstacles were: Training on different levels that helps build, both, communities of interested users, and new experts critical to sustain the transformation, platforms that let people start using a new technique right away, and strategic software development to bridge the gap between established data formats and new tools. The second part of this talk gives an overview of platforms and software we developed or contributed to in order to specifically pave the way of NEMO users to massively parallel analytics. With this, we enabled many users to achieve tasks that previously would simply have been in-feasible.

12. Pangeo: Confronting Oceanography's Big Data Problem

Ryan Abernathey

Lamont Doherty Earth Observatory, Columbia University, Palisades. Contact: rpa@ldeo.columbia.edu

Satellite observations and high-resolution ocean simulations are now generating extremely large volumes of data (getting into the petabyte range). These high resolution datasets have the potential to drive progress on fundamental questions in physical oceanography, such as how energy transferred and dissipated across scales. However, analyzing such datasets efficiently is a major technical challenge. The Pangeo is an international collaboration that grew out of the open-source scientific python software community. Our goal is to integrate existing technologies in order to build highly flexible, scalable, and productive environments for climate data science. The central idea is to provide interactive computing resources in close proximity to wherever the datasets are stored. These environments can be deployed on traditional HPC clusters or using commercial cloud services. The main python packages comprise these environments are Jupyter, Xarray, and Dask. My talk will describe our progress so far, explain how the Drakkar community might participate and benefit, and speculate about the future role of Pangeo in facilitating machine-learning approaches in oceanography.

Session 2
Improving ocean models for climate and operational applications

13. Tiling and time-levels

Mike Bell, Maff Glover, Gurvan Madec
(1) U Met Office Hadley Center, Exeter, (2) LOCEAN, Paris.

14. Overflow representation in local sigma coordinates at 1/12o and 1/4o.

Pierre Mathiot (1), Pedro Colombo(2), Helene Hewitt (1), Bernard Barnier (2), James Harles (1)
(1) U Met Office Hadley Center, Exeter, (2) IGE, Grenoble.

15. Challenging vertical turbulence mixing schemes in a 3D shelf-sea model versus observations. What processes we miss in turbulent closure schemes.

Maria Luneva et al,
NOC- Liverpool, UK.
In 3d decadal timescale simulations (1996-2012), we assess sensitivity of NEMO-shelf model for the North-West European shelf to the choice of stability functions in turbulence closure scheme. We compared simulations with 8 different vertical mixing schemes with available measurements of hydrography and find that all turbulence closures simulate pycnocline depths too shallow, strength of pycncoline is too weak and benthic temperatures are warmer compared with observed. In this study we also assess simulation versus available observations of dissipation rate of turbulent kinetic energy (20 datasets). Simulated dissipation rate has an order negative biases in subsurface layer and absence of correlations in pycnocline. The latter we relate to improper parameterisations of internal tidal wave mixing in pycnocline. Using SAR images we identify the locations of active internal solitary waves, and find that most of the location with poorly simulated dissipation rate are co-allocated with observed zones of energetically SARs. We examine unresolved processes, missed in models: effects of young waves, increasing transfer of momentum to the mixed layer and enhancing wave breaking, comparing with equilibrium regime, Langmuir circulations and non-standard near inertial oscillations (NNIO), related with northward component of Coriolis force. Using ERA-5 high-resolution reanalysis dataset we evaluate probability of each of this processes. Each of these processes occupies their own niche in physical parameters space and region.
Simulations coupled with ecosystem model show the choice of turbulence closure strongly affects the ecosystem behaviour, shifting the timing of peak chlorophyll by one month, and

showing regional chlorophyll differences of order 100%. There is no clear "winner" out of this range of closures, with different closures showing the best results for different metrics, so the ultimate choice needs to be application dependent.

16. First steps with z-tilde in a 1/4° global NEMO

Alex Megann

National Oceanography Centre, Southampton. Contact: apm@noc.ac.uk

The eddy-permitting 1/4° resolution in NEMO is known to suffer from significant numerical diapycnal mixing. A major contribution to this is ascribed to truncations in the advection scheme: transient vertical motions from partially-resolved eddies, internal tides and near-inertial waves lead to spurious mixing of tracers in the model, where in the real ocean such motions manifest mainly as adiabatic heave and do not lead directly to mixing. Suppressing the near-gridscale noise by increasing the viscosity has been shown to offer a useful reduction in this numerical mixing, but this does not have a significant effect on tides and inertial waves.
The z~ ("z-tilde") scheme of Leclair and Madec (2012) replaces eulerian flows across the vertical coordinate surfaces on time scales less than a few days with displacements of the coordinate surfaces themselves, in a manner more consistent with the nearly adiabatic nature of internal waves and tides, which occur on near-inertial time scales. This has been shown to give substantial reduction in numerical mixing in an idealised configuration, and is currently being tested in regional models, but has yet to be evaluated in a global ocean configuration. Under the RENUMERATE project, the new prototype GO8 eORCA025 NEMO v4 configuration is used as a testbed to assess the effect of tidal forcing on numerical mixing, and to test the effectiveness of z~ as a tool to ameliorate the latter. Preliminary results will be presented, including evaluation of the effective diffusivity with and without z~.

Sharing and citing NEMO configurations: A proposal for a protocol and software toolbox

Markus Scheinert

GEOMAR, Kiel

Introduction to Discussion session #1

17. Sensitivity experiments on sub-grid-scale parameterizations with eORCA025

Julie Deshayes

LOCEAN, Paris

The climate model IPSL-CM6-MR025, as well as other candidates to CMIP6, has for its ocean component an eddy-permitting configuration, namely NEMO eORCA025. With a nominal resolution of 1/4 at the equator, the grid spacing remains insufficient to represent mesoscale and sub-mesoscale processes nearly everywhere except in the tropics. There are various methods available in NEMO platform to represent the effect of sub-grid-scale processes. We performed a suite of decadal experiments, forced by realistic atmospheric conditions, to clarify the impact of a selection of these methods, independently and conjointly with others, on ocean essential variables (SST, SSS, MLD, AMOC, ACC, gyres...). Final choice of parameters for IPSL-CM6-MR025 will be discussed.

18. The degrees of freedom of turbulent mixing in the ocean and implications for mixing parameterisations

Remy Tailleux
University of Reading
The turbulent fluxes of heat and salt can be viewed as a 6-dimensional state vector at every point in the ocean that most ocean mixing parameterisations try to represent by using only 3 mixing parameters. How can this work?

19. Atlantic Meridional Overturning in the Coupled Model FOCI with Ocean Nesting

Jan Harlaß (1), Torge Martin (1), Arne Biastoch (1,2), Katja Matthes (1,2)
(1) GEOMAR, Kiel, (2) Christian Albrechts University, Kiel
The new Flexible Ocean and Climate Infrastructure (FOCI) combines fundamental parts of the Earth System. Alongside with a global high-top atmosphere (ECHAM6) and ocean model (NEMO3.6), sea ice and land surface models provide the backbone of the system. Atmospheric chemistry and ocean biogeochemistry modules are available as choices. A prominent feature of FOCI is the ability to enhance ocean resolution in a specific area of interest, so-called nesting, in a fully coupled model framework. We will present these new capabilities of the model system and provide examples for its applications. We will further shed light on the impact of regionally resolving the oceanic mesoscale on the Atlantic meridional overturning circulation (AMOC) in coupled mode. Compared to forced ocean models, a coupled model allows for atmosphere-ocean-feedbacks. Hence, the overlying atmosphere is an additional path for teleconnections outside the nest domain. Results of two separate nest configurations at 1/10° horizontal resolution in the South Atlantic and Indian Ocean (INALT) as well as in the North Atlantic (VIKING), embedded into a global 1/2° model, are presented. Both heat and salt exchange with the Indian Ocean through Agulhas leakage as well as deep convection in subpolar North Atlantic are key processes shaping strength and variability of the AMOC. For both processes mesoscale ocean dynamics were shown to be crucial. The role of atmospheric feedbacks is studied as both nested model configurations are run in coupled and forced (hindcast) mode. First results show that the AMOC is considerably stronger in the coupled climate model, i.e. with atmospheric feedbacks. With VIKING AMOC strengthens as complex structures related to deep-water formation in the subpolar North Atlantic are represented more realistically in both coupled and forced mode. Yet, AMOC strength is less affected by resolving mesoscale features in the South Atlantic (INALT) in coupled mode, contrary to forced integrations. This indicates the complexity of feedbacks when introducing atmosphere-ocean coupling and oceanic mesoscale dynamics to the system. As an example, meridional heat and freshwater transports respond stronger to a South Atlantic nest in coupled mode, leading to changes well outside the nest domain. Deep-water formation in the Nordic Seas, sea ice properties, heat fluxes and wind stress across the northern North Atlantic change with a coupled South Atlantic Nest, compared to the un-nested coupled configuration.

20. Coupling a spectral wave model with a coupled ocean-ice model: impact on lateral melting, effects on the ice edge and sea surface properties

Guillaume Boutin, Camille Lique, Fabrice Ardhuin
LOPS, Brest.
Sea ice representation in climate models remains incomplete, largely because different processes are poorly understood. One such process is the effect of surface waves in the Marginal Ice Zone. Adding a simple sea ice representation in numerical wave models has already already provided new opportunities to investigate the impact of such interactions, and the next step is to improve the ice behaviour when it experiences wave events. To this end, the ocean/sea ice

model NEMO-LIM3 has been coupled with the wave model WAVEWATCH III using OASIS-MCT.
WAVEWATCH III includes a sea ice representation which is expected to apply to a variety of ice conditions with the exception of forming ice. In this model, the ice is treated as a single layer that can be fractured into many floes with a given size distribution that is defined from the maximum diameter, Dmax, and a fragility parameter. This layer of ice induces a dissipation of the wave energy through basal friction and dissipation associated with ice flexure, in addition to an energy-conserving scattering (Boutin et al., JGR, 2018). Besides the impact on some attenuation processes, this break-up is expected to increase the lateral melt (Asplin et al., JGR, 2012) and let the floes drift freely (Williams et al., The Cryosphere, 2017), but such features could not be included in the wave model.
Our coupling enables NEMO-LIM3 to receive Dmax from WAVEWATCH3 from which the floe size distribution (FSD) is rebuilt and advected following Zhang et al. (Ocean Model. 2015). This FSD is then used in the lateral melt computation, and finally sent back to WAVEWATCH III along with the ice concentration and thickness. Additionally, the wave attenuation is associated with a loss of momentum, resulting in a radiative stress which pushes the ice in the direction of the attenuated waves (Longuet-Higgins, Proc. R. Soc. A., 1977). This stress is computed in WAVEWATCH III and provided to the ice model.
After a validation of the coupling using tests with simplified geometry, the coupled model is run on a 1/4° pan-Arctic grid. At regional scale, wave events can strongly affect the ice drift through the radiative stress, with strong feedbacks on the location and intensity of the sea ice melt, thus affecting the sea surface temperature and salinity. Oppositely to the parametrization of Lupkes et al. (JGR, 2012), the use of a sea state dependent floe size only yields lateral melt whithin the ice edge, where it is expected to happen, and also impacts the sea surface properties.

21. Work on the coupled NEMO-neXtSIM system

Einar Olason
NERSC, Bergen. Contact: Einar.Olason@nersc.no
We present NANUK, a coupled ice-ocean model consisting of the ocean core of NEMO (OPA) and the next generation sea-ice model neXtSIM, coupled through the OASIS coupler. Firstly, we present the neXtSIM model briefly, outlining its uniqueness and grounds for exploring the coupled ice-ocean system using neXtSIM. We then address the primary technical challenge of coupling neXtSIM with another model, which lies in the fact that neXtSIM uses a moving, Lagrangian mesh. Finally, we show some preliminary results for a simulation of the Arctic and North-Atlantic (using the CREG setup).

22. ACCESS-OM2: An ocean-sea ice model at 3 resolutions

Andy Hogg
ANU, Canberra
We introduce a new version of the ocean-sea ice implementation of the Australian Community Climate and Earth System Simulator, ACCESS-OM2. The model has been developed with the aim of being aligned as closely as possible with the fully coupled (atmosphere-land-ocean-sea ice) ACCESS-CM2. In addition, the model is available at three different resolutions: a coarse resolution (nominally 1°), an eddy-permitting resolution (nominally 0.25°) and an eddy-rich resolution (0.1° with 75 vertical levels). The different resolutions have been developed simultaneously, both to allow testing at low resolutions and to permit comparison across resolutions. In this talk, I will outline the development of this model, which is largely based on the DRAKKAR formulation, and show a preliminary evaluation of model performance across the three

different resolutions, highlighting the relative advantages and disadvantages of running ocean-sea ice models at higher resolution.

23. Improving NEMO's iceberg module

Juliana Marson, and Paul Myers

University of Alberta, Edmonton

Icebergs constitute a major part of ice sheets mass discharge, delivering freshwater to the ocean at a slower pace than direct coastal runoff. They are also linked to phytoplankton blooms since their meltwater contain a number of terrigenous nutrients. Added to those environmental roles, icebergs pose a threat to shipping and offshore resources extraction activities. Since monitoring every individual iceberg is an operational impossibility, numerical models are useful tools to explore their common trajectories and impacts on the ocean. NEMO v3.6 has introduced an iceberg module that was originally built by Bigg et al (1996,1997) and further improved by Martin and Adcroft (2010) and Marsh et al. (2015). In this original version, icebergs are driven and deteriorated by surface ocean fields. Since then, Merino et al. (2016) has tested a new scheme (not yet included in NEMO) where ocean fields are vertically-integrated between surface and iceberg keel before being used in the dynamic-thermodynamic equations for icebergs. Since their simulation focused on Antarctic icebergs, we have applied their new scheme to Greenland and compared iceberg trajectories with the ones obtained with the original surface-only scheme. We found that icebergs that are driven by the vertically-integrated ocean velocities concentrate along the shelf break (following the geostrophic component of currents) while in the original version they drift close to the coastline. We are now further modifying NEMO's iceberg module in order to lock icebergs that get caught in a concentrated and strong sea ice pack. Future plans also include modifying how the meltwater enters the ocean. Although icebergs drifting within weak flows have their meltwater injected close to the surface (which is what the original module does), the ones embedded in stronger flows have their meltwater plume entering at depth (Fitz Maurice et al., 2017). The challenge will be to find an appropriate way to reduce subsurface salinity without creating strong instabilities.

Session 3
Understanding ocean-ice-atmosphere interactions and their consequences for ocean modelling strategies

24. Recipes how to best force an ocean model

Lionel Renault

LEGOS Toulouse. Contact: lionel.renault@ird.fr

25. Recent developments in NEMO within the ALBATROSS project for an improved representation of ocean/waves/atmosphere interactions

Florian Lemarié (1), G. Samson (2), X. Couvelard (3), J.-L. Redelsperger (3), G. Madec (4), R. Bourdallé-Badie (2), H. Giordani (5)

(1) LJK, Grenoble, (2) Mercator Ocean, Toulouse, (3) LOPS, Brest, (4) LOCEAN, Paris, (5) CNRM, Toulouse. Contact: florian.lemarie@inria.fr.

Within the ALBATROS project, the objective is to improve the representation of key processes associated to air/sea/waves interactions in global eddying simulations, i.e. at the characteristic scales of the oceanic mesoscale.

First, a generic coupling interface to a surface wave model has been developed and the NEMO governing equations and boundary conditions have been adapted to include wave-induced terms following the approach of McWilliams et al. (2004) and Ardhuin et al. (2008). In particular, the contributions of Stokes-Coriolis, Vortex and surface pressure forces have been implemented on top of the necessary modifications of the turbulent closure scheme (a 1-equation TKE closure here).
Second, a simplified model of the Atmospheric Boundary Layer (ABL) of intermediate complexity between a bulk parameterization and a full three-dimensional atmospheric model is currently under development and has been integrated to the NEMO surface module. We describe the implementation of the NEMO-ABL coupling infrastructure as well as the current formulation of the ABL model. Results obtained for some atmosphere-only simplified test-cases available in the literature are shown.

26. Development of a 2-way coupled ocean-wave model: assessment on a global oceanic configuration

Xavier Couvelard (1), Florian Lemarié (2), Guillaume Samson (3), J.ean-Luc Redelsperger (1), Fabrice Ardhuin (1), Rachid Benshila (4) and Gurvan Madec (5)
(1) LOPS, Brest, (2) LJK, Grenoble, (3) Mercator Ocean, Toulouse, (3), (4) LEGOS, Toulouse, (5) LOCEAN, Paris.
The objective of ALBATROS project is to improve the representation of the interactions between ocean, waves, and atmosphere in a global forecasting model at high resolution in the scope of CMEMS (Copernicus Marine Environment Monitoring Service). A part of this project is to couple the waves model WW3 with the ocean model NEMO thanks to OASIS3-MCT.
As a first step toward operational implementation, it as been chosen to implement the coupling on the global configuration ORCA025 (1/4 degree).
In this talk, we (i) describe briefly the coupling terms, (ii) show the impacts of waves on the wind forcing, and (iii) focus on how better representing the effect of waves thanks to a wave modified TKE module including new wave dependent surface boundary condition and Langmuir Circulation parameterization, can improve summer MLD distribution when compared to ARGO data. Deeper MLDs results in reduced surface current and reduced SST.

27. Surface wave energy in sea ice covered regions: where does it go and does it matter?

Stefanie Rynders (1), Yevgeny Aksenov(1), Lucia Hosekova(2), Danny Feltham(2), George Nurser(1)
(1) National Oceanography Centre, Southampton. (2) University of Reading.
Surface waves are an important phenomenon in the ice covered regions. Because of climate change waves are becoming more prevalent in the Arctic and possibly also in the Southern Ocean. Through modification of energy and momentum transfers between the atmosphere, sea ice and ocean waves can influence climate feedbacks and potentially accelerate sea ice retreat. We present a strategy to implement "partial" (with forced atmosphere) coupling in WW3-CICE/SI3-NEMO system, discuss different mechanisms of wave momentum transfer into the ocean and demonstrate how waves affect sea ice and ocean.

28. Air-sea coupling at the mesoscale

Sophia Ashby (1), David Ferreira (1), Malcolm Roberts (2) and Helene Hewitt (2)
(1) University of Reading, UK, (2) Met Office Hadley Centre, UK
Air-sea coupling at the mesoscale is an exciting, relatively new area of research dependent on the availability of high-resolution ocean and atmospheric data. Previous observational studies

demonstrate how, at the mesoscale, the ocean drives atmospheric changes through heat, momentum and freshwater fluxes : increased wind speed, vertical mixing in and the height of the atmospheric boundary layer, increased latent and sensible heat fluxes, rainfall and cloud cover are all associated with a warm SST anomaly within an anti-cyclonic eddy (and vice versa for a cyclonic eddy) [e.g. Frenger et al., 2013]. A limited number of studies explore the horizontal model grid resolution in both the atmosphere and ocean (and the ratio in-between the two) needed, to accurately represent these small scale air-sea fluxes, in high-resolution coupled climate models. We use a 'composite analysis' technique, to average all eddies globally, to explore how air-sea fluxes over mesoscale eddies are distorted through the spatial re-gridding of the ocean to the atmosphere. High resolution configurations of the coupled climate model HadGEM3-GC3.1 (N216-025, N216- 12 and N512-12) are used.

The air-sea heat flux feedback dampens SST anomalies, and is important for setting surface boundary conditions in ocean-only models. This feedback coefficient varies seasonally and according to spatial scales, with an increase found at smaller scales [Hausmann, Czaja and Marshall, 2016]. We use this coefficient to compare the ratio of model resolutions, and predict ocean SST anomalies within mesoscale eddies are not 'dampened' enough through existing air-sea turbulent heat flux equations in coupled models. Finally we diagnose the correct feedback factor, showing its dependence on the atmosphere-ocean 're-gridding' of SST, atmospheric adjustment and air-sea flux coefficients.

29. Atmosphere-Wave-Ocean-Sea-Ice Coupling for numerical weather prediction (NWP): Issues and challenge.

Kristian Mogensen, Sarah Keeley, Jean Bidlot, Simon Lang, Frederic Vitart, Magdalena Alonso Balmaseda, Gianpaolo Balsamo and Nils Wedi

European Centre for Medium-Range Weather Forecasts, Reading

Since the introduction of the coupling into the high-resolution deterministic model (HRES) in June 2018 all ECMWF issued forecasts are based on a coupled atmosphere-wave-ocean-sea-ice model where the ocean and sea-ice models are based on NEMO version 3.4.1 with LIM2 as the sea-ice model. We will show some examples on situations where an interactive ocean and sea-ice improves the weather prediction and discuss the ocean model requirements for these time scales.

For NWP, we want to keep the cost of the ocean low so we want to make some compromises to maximize benefits of coupling to the ocean with minimum costs. It has been shown that mesoscale eddies and boundary currents can influence the prediction of weather over Europe, but it is not feasible to run an eddy resolving configuration like the ORCA12 when we run 51 ensemble members twice a day. We will show how we have implemented a scheme to couple tendencies in the first days rather than full fields (partial coupling) and discuss pros and cons of these schemes in terms for atmospheric performance and the lack of consistency between the ocean and the atmosphere components.

30. Understanding air-sea interactions at the mesoscale around Australia

Guillaume Sérazin (1), Alex Sen Gupta (1), Alejandro Di Luca (1), Nicolas Jourdain (2), Daniel Argüeso (3)

(1) UNSW-Climate Change Research Centre, Sydney, (2) IGE Université Grenoble Alpes, Grenoble, (3) University of Balearic Islands, Palma de Mallorca.

The Australian first Regional Coupled Model, which couples NEMO and WRF with OASIS, is used to assess the importance of resolving high-resolution air-sea interactions at the mesoscale 0(100 km) to better coupled processes under the present climate and to forecast future climate. The impact of the ocean current feedback to the wind stress is found to be substantial all around Australia and provides a sink of eddy kinetic energy in the ocean through an eddy-killing effect, while releasing energy to the surface atmospheric winds. As mesoscale eddy statistics are modified by this mechanical feedback, the transport of the East Australian Current and the position of the Tasman front undergo substantial changes. The influence of the current feedback on low-pressure systems, such as East Coast Lows, is also investigated and differences are shown to be non-negligible with the current feedback increasing intense wind events.
This coupled model is also used to investigate future changes under the RCP8.5 scenario, taking into account the influence of oceanic mesoscale eddies and the associated thermal and mechanical feedbacks.

31. Ocean Surface Dynamical Response to Perturbations in the Large-Scale Atmospheric Circulation

Margarita Markina, Joshua Studholme, Sergey Gulev
Shirshov Institute of Oceanology, Russian Academy of Science, Moscow. Contact: markina@sail.msk.ru
Wave climate in the Southern Ocean is poorly understood and is a key local thermodynamic control through its impact on the surface ocean mixed layer. Wave climate there is notably complex since it is driven by numerous low-frequency oscillations such as the Southern Annular Mode and ENSO. This complexity limits confidence in long-term projections. To approach this problem, we use an idealized aquaplanet AGCM to modify the large-scale meridional temperature gradient and thus simulate responses in tropospheric jet streams and large-scale atmospheric overturning cells. To study the impact of large-scale atmospheric dynamics on waves formation and corresponding wave-induced mixing we dynamically force a spectral wave model with this idealized atmospheric circulation. Wave-induced production of turbulence is parameterized via vertical kinematic diffusivity computed from the wave energy spectra. This is based on Reynolds stresses using Prandtl's mixing length hypothesis in which mixing length is considered to be proportional to wave amplitude.
The results demonstrate that relaxation/exaggeration of the meridional SST gradient implies changes in the tropical atmosphere that leads to equatorward/poleward shifts in jet streams and modulation of their intensities. This likewise causes corresponding modulation of surface wind distribution. However, the quasi-linear pattern in surface stress changes are found to result in non-linear responses in wave heights with larger non-linearity in the wave-induced mixing and consequently the depth of effective vertical mixing. Though the dynamical response of the ocean surface layer to atmospheric perturbations is not limited to wave-induced mixing, this source of turbulence has recently emerged as a particularly underestimated contributor and has been shown to result in temperature biases in ocean circulation models. These results emphasize that relatively small changes in large-scale atmospheric circulation can lead to the non-linear response of the ocean surface wave climate and impact the ocean mixed layer depth. These conclusions have particular relevance for understanding changes in the Southern Ocean.

32. FOCI-OpenIFS: A test balloon for coupled high-resolution simulations

Joakim Kjellsson, Wonsun Park, Mojib Latif
GEOMAR, Kiel

We study the variations in air-sea interactions across different horizontal length scales using a climate model, FOCI, run at various resolutions. At higher horizontal and vertical resolution, the atmosphere model is capable of capturing short-lived, localised extremes in precipitation and wind speed, which impacts the air-sea exchange of momentum and freshwater. Furthermore, studies suggest that increasing the horizontal resolution of the ocean component leads to more intense air-sea fluxes of heat and freshwater.
The FOCI-OIFS v1.0 climate model is based on OpenIFS cy40r1 and NEMO/LIM v3.6 run at 1.125° and 0.5° resolution respectively, with the possibility to increase ocean resolution to 0.1° regionally using AGRIF two-way nesting. OpenIFS can be run at a variety of horizontal resolution. The development and set up of this model will be presented as discussed.

33. Overview of coupled model and assimilation developments at the European Centre for Medium-Range Weather Forecasts

Nils Wedi, Magdalena Balmaseda, Gianpaolo Balsamo, Anton Beljaars, Jean Bidlot, Phil Brown, Marcin Chrust, Sarah Keeley, Simon Lang, Patrick Laloyaux, Kristian Mogensen, Patricia de Rosnay, Frederic Vitart, Hao Zuo
European Centre for Medium-Range Weather Forecasts, Reading

The coupling of atmosphere, land-surface, ocean, sea-ice, and waves in ECMWF's Earth-system model requires a careful consideration of the highly varying temporal and spatial scales of the individual processes at the interfaces and their consistent initialisation. Parameters such as skin temperature over land or sea surface temperature are well observed from satellite observations but are complex to model in dynamically coupled systems. This talk will describe the current state and future plans for the integration of the NEMO ocean, LIM/SI3 sea-ice, and waves into ECMWF's forecasting and reanalyses applications. A particular emphasis is on the consistent initialisation of the ocean and sea-ice components and their impact on the atmospheric analyses and atmospheric predictability of subsequent short, medium-range, extended-range and seasonal forecasts.

34. JRA55-do with NEMO ocean models

Patrick Wagner, Markus Scheinert, Claus Böning
GEOMAR, Kiel.

We present a set of two hindcast experiments of a global ocean model forced with the established dataset COREv2 and the new JRA55-do product (Tsujino et al. 2018). JRA55-do offers an improved temporal and spatial resolution and covers the period from 1958 to 2017, which makes it a promising alternative to COREv2. We present a direct comparison of selected features of the global circulation. We show that the new JRA55-do forced simulation is able to overcome known deficits of its COREv2 forced counterpart, such as too strong sea surface height trends in the tropical Pacific.
In addition to these successful hindcast simulations, we conducted "Repeated Year"-experiments. Instead of building an artificial, climatological forcing, representative years were chosen and used repeatedly to force a full model cycle. These experiments help to analyse internal, interannual variability, unrelated to the atmospheric forcing, and identify spurious model trends.

35. Influence of atmospheric forcing on modelling the North Atlantic sub-polar gyre.

Paul Myers and Clark Pennely

University of Alberta, Edmonton
The North Atlantic sub-polar gyre contains regions which experiences intense air-sea exchange during convective winter periods. With large amounts of buoyancy loss via both latent and sensible heat, there are weakly stratified regions within the sub-polar gyre capable of deep convection. Numerical simulations are excellent tools to examine the effects of deep convection in these regions, though the atmospheric forcing datasets available can differ significantly. We evaluated five atmospheric forcing datasets with different spatial and temporal resolution: DFS5, ERA-Interim, CORE2/NCEP, JRA55, and the Canadian Meteorological Centre's Global Deterministic Prediction System (CGRF).
With variability between the five forcing fields, each dataset prescribes different conditions over the ocean. This will result varying heat transport between the atmosphere and the ocean, precipitation minus evaporation differences, culminating in varying levels of buoyancy removal over convective regions. We investigate both the differences between the atmospheric products as well as simulations forced by each product. We compare the differences carried out by these five simulations on convective regions around the sub-polar gyre, specifically focusing on the subduction rate and density class of the deep-water produced.

36. A model study of the sensitivity of the Atlantic Water subduction processes to sea-ice conditions

Claude Talandier, Camille Lique, Verena Haid
LOPS, Brest.
The inflow of Atlantic Water (AW) is the main source of heat for the Arctic Ocean. Along its path from the Nordic Sea to the entrance of the Arctic through Fram Strait and the Barents Sea Opening, AW loses a significant amount of heat to the cold atmosphere. Further, AW penetrates in the Marginal Ice Zone (MIZ) and then the ice pack, where it continues to cool through its interaction with sea ice, resulting in its subduction under a cold and fresh surface layer (the halocline).
In a wide range of ocean-sea ice models, a bad representation of the complex AW subduction processes, locally at the entrance of the Arctic Basin, might lead to basin-scale biases of the water masses properties in the Arctic, and in particular of the temperature and depth of the AW layer.
The goal of this study is to explore the sensitivity of the AW subduction to sea-ice model parameters using a regional Arctic-North Atlantic configuration at 1/4° based on the NEMO v3.6 and LIM3 sea-ice model.
We find that small changes of some sea ice model parameters (within the range of values used in the literature), such as the sea ice strength and the ice-ocean drag coefficient, can modify strongly the sea ice conditions in the Fram Strait region, leading to a strong sensitivity of the processes at play for the AW subduction and the large scale AW properties.

37. Investigating the dynamics of the Beaufort Gyre with a high-resolution model

Heather Regan, Camille Lique, and Claude Talandier
LOPS, Brest.
The Arctic freshwater system supplies freshwater to the North Atlantic and stores large quantities of freshwater within its interior. Studies suggest that variability in Arctic freshwater export has the potential to affect global thermohaline circulation, and therefore the wider climate system. The Beaufort Gyre, in the Canadian Basin of the Arctic, is a significant reservoir of freshwater, and acts to modulate freshwater export to the North Atlantic. In recent decades, its sea surface height (SSH) and freshwater content have increased as a consequence of spin-up

and extension of the gyre. The dynamics of the gyre, and particularly the role of eddies, are still not fully understood. First, we use a satellite altimetry dataset that provides SSH in ice-covered regions to describe the spatial and temporal characteristics of the gyre over 2003-14. We illustrate the respective roles of the atmospheric forcing and the bathymetry for setting up the state of the gyre. Secondly, we expand our analysis by using model output from the CREG12 configuration. We show that the model is successful at reproducing the observed behaviour of the gyre. The model results allow us to quantify the importance of the mesoscale activity for the gyre dynamics, and its response to a spin up or spin down of the gyre. It also helps us to contrast the energetics of the gyre in presence or absence of bathymetry.

38. Changing Advective Pathways of nutrients in the Arctic: High-Resolution modelling of biogeochemistry and ocean circulation

Yevgeny Aksenov (1), Ben Rabe (2), Andrew Yool (1), Katya Popova (1), Myriel Horn (2), Stefanie Rynders (1), Maria Luneva (1), Céline Heuzé (3), Michael Karcher (2), Hiroshi Sumata (2), Sinhué Torres

(1) National Oceanography Centre, Southampton, (2) Alfred Wegener Institute, Bremerhaven, (3) University of Gothenburg. Contact: yka@noc.ac.uk.

We present an overview of the project "The Advective Pathways of nutrients and key Ecological substances in the Arctic (APEAR)", funded under the UK-Germany joint "Changing Arctic Ocean" Programme. The project uses high-resolution (~2-9 km) global coupled simulations of the biogeochemistry and ocean circulation with NEMO-Medusa. We focus on the shifts of the advective pathways of the nutrients and iron. The present-day ocean state and forward projections are under analysis, specifically the changes in the ocean circulation in the Eurasian and Canadian basins of the Arctic Ocean and coupling of the these basins. We discuss the role of the boundary currents and sea ice retreat in the current and projected future changes in biogeochemistry and ecosystems. The observational component of the project contributes to the R/V Polastern drift MOASiC taken place in 2019-20. We present a brief overview of the planed measurements.

39. Functioning of the MOC: lessons from past and future climates

Camille Lique, Yurui Zhang, Thierry Huck, Matthew Thomas

LOPS, Brest

The Meridional Overturning Circulation (MOC) is a key element of the global climate system, which transports large amounts of water, heat, salt or carbon around the globe, and connects the surface ocean and atmosphere with the huge reservoir of the deep sea. In our present-day climate, these sites of deep water formation are located in the Southern Ocean around Antarctica, and in the Subpolar region, in the Labrador, Irminger and Nordic Seas. Using fully coupled climate simulations, the goal of this presentation is to investigate how this functioning may vary when considering different climate states.

First, we use simulations representative of a future, warmer climate, and reveal that the regions where dense waters contributing to the deeper branch of the Atlantic Meridional Overturning Circulation (AMOC) are formed are likely to shift both southwards, to the Atlantic subtropical gyre, and northwards, to the Arctic Basin, due to changes in background stratification, mixed layer depth and ocean circulation.

Second, we analyse simulations of the warm Ypresian geological period (55 million years ago), during which dense water are only formed in the Southern Hemisphere. The analysis of the oceanic heat transport associated with the MOC and the wind-driven circulation provides some insights on the importance of the bathymetry to set the state of the climate.

40. Wind-driven oscillations of cross-equatorial Meridional Overturning Circulations

Adam Blaker (1), Joel Hirschi (1), Mike Bell (2)
(1) National Oceanography Centre, Southampton, (2) Hadley Centre, Exeter
Numerical simulations performed with an eddy-permitting global ocean model (NEMO) suggest the existence of large amplitude equatorial oscillations in the Meridional Overturning Circulations (MOCs) in the Atlantic, Pacific and Indian oceans. Their amplitude is proportional to the width of the ocean basin and is typically ~200 Sv in the Pacific. We conduct a series of experiments in which we fix the wind forcing over parts of the domain. These experiments show that the oscillations are a response to the local wind variability, which excites low baroclinic mode equatorially trapped inertia-gravity waves. Previously published observations from the TAO/TRITON mooring array in the equatorial Pacific show peaks in the power spectrum of surface dynamic height at periods close to 5.5 and 7 days. These peaks are in good agreement with the signals seen in the simulations and closely correspond to the theoretical dispersion relations for low baroclinic mode equatorially trapped inertia-gravity waves.

Session 4
Atmospherically forced vs intrinsic ocean variability, uncertainties and ensemble strategies
(Poster Session)

41. Estimating the forced and intrinsic contributions to sea surface height variability without an ensemble

Sally Close (1,2), Thierry Penduff (1), Sabrina Speich (2)
(1) IGE, Grenoble, (2) LMD/ENS, Paris.
A common goal of ensemble modelling approaches is to obtain probabilistic information concerning the behaviour of the system under consideration. It is often of interest to estimate a deterministic contribution, common to all the ensemble members (the ensemble mean), and separate this from the total signal, yielding the intrinsic contribution as the residual of each member. The ensemble methodology is useful, in that it permits the realisation of this aim, but also has certain disadvantages: amongst the most notable of these are the very high computational expense associated with the production of the ensemble, and the impossibility of applying the same approach in an observational context. Motivated by this problem, the temporal and spatial properties of the forced and intrinsic contributions to sea surface height variability derived from the OCCIPUT ensemble experiment are analysed, and a simple means of estimating the two contributions based on a single experiment derived. The methodology is tested on a single ensemble member, before being applied to the observed altimetric record. The two sets of outputs show good consistency, suggesting potential uses for the method in both model development and climate attribution contexts.

42. E Contributions of atmospheric forcing and chaotic ocean variability to regional sea level trends over 1993-2015

William Llovel (1), Thierry Penduff(2), Benoit Meyssignac(1), Jean-Marc Molines(2), Laurent Terray(3), Laurent Bessières(3), Bernard Barnier(2)
(1) LEGOS, Toulouse, (2) IGE, Grenoble, (3) CERFACS, Toulouse.

As a direct consequence of the ongoing global warming, global mean sea level has risen in response to global ocean warming and continental ice melting from ice sheets (Greenland and Antarctica) and mountain glaciers. Since the early 1990s, satellite altimetry has become the main observing system for continuously measuring the sea level variations. Satellite altimetry has revealed a global mean sea level rise of 3.3 mm/yr since 1993 with large regional sea level trends that differ from the global mean estimate.

A global ¼° ocean/sea-ice 50-member ensemble simulation is analyzed to disentangle the imprints of the atmospheric forcing and the chaotic ocean variability on regional sea level trends over the satellite altimetry period. We find that the chaotic ocean variability may mask atmospherically-forced regional sea level trends over 38% of the global ocean area from 1993 to 2015, and over 47% of this area from 2005 to 2015. These regions are located in the western boundary currents, in the Southern Ocean and in the subtropical gyres. While these results do not question the anthropogenic origin of global mean sea level rise, they give new insights into the intrinsically oceanic versus atmospheric forcing of regional sea level trends, and provide new constraints on the measurement time required to attribute regional sea level trends to the atmospheric forcing or to climate change.

43. Forced and Chaotic Variability of the Gulf of mexico and surrounding regions: An ensemble simulation approach

Ixelt Garcia Gomez, Thierryn Penduff, Bernard Barnier, jean-Marc Molines
IGE, Grenoble.

44. Disentangling the intrinsic from the forced variability in a low-order ocean model through different ensemble simulation strategies

Stephano Pierini
Università di Napoli Parthenope

The global pullback attractor (GPBA, e.g., Ghil et al., 2008) of a chaotic dissipative dynamical system subjected to time-dependent forcing implies full statistical knowledge of the system, as it tells which states the system can assume at any time instant, and with what probability. The GPBA of a four-variable double-gyre quasigeostrophic ocean model (Pierini, 2011) has recently been derived through ensembles of many thousands of simulations in several situations (Pierini, 2014; Pierini et al., 2016 2018). In this presentation, new results are discussed concerning the same model forced by a schematic North Pacific wind stress field including both a high- and a low-frequency component. The knowledge of the system's GPBA is exploited to disentangle the intrinsic oceanic variability from the atmospherically forced variability.

In realistic high-resolution ocean modelling, determining the system's GPBA is computationally prohibitive, but ensemble simulations with a limited but significant number of members can nonetheless be carried out (e.g., Penduff et al., 2014; Bessières et al., 2017; Leroux et al., 2018). The same approach has been adopted with the low-order ocean model. Knowledge of the GPBA -available in this case- allows one to assess the statistical significance of the small ensemble simulation approach and, at the same time, suggests new strategies that could improve the identification of the low-frequency oceanic variability of intrinsic origin.

Posters

45. Sensitivity of bathymetric steering to the formulation of the Coriolis term in ORCA025.

Dave Storkey

Met Office Exeter. Contact: dave.storkey@metoffice.gov.uk

NEMO 4 has a large number of choices for formulation of the vorticity (dynvor.F90) and momentum advection (dynadv.F90). A comprehensive set of tests (similar to those inLe Sommer et al 2009) is presented of the various options in ORCA025. The steering of currents by the bathymetry in the northwest Atlantic is sensitive to the choice of vorticity scheme, with a bimodal distribution of schemes that have strong steering and schemes that have weak steering. There is much less sensitivity to the choice of momentum advection scheme (vector invariant or flux form). Examination of the vorticity trends in an idealised model of the shelf break shows that there is a truncation error associated with the bathymetry, which varies in a systematic way with the relative orientation of the slope and the grid. This is reminiscent of the dependence on coastline - grid orientation discussed in Adcroft and Marshall 1998 and Dupont et al 2003.

46. Estimating High resolution Global Surface Currents with Machine Learning.

Anirban Sinha, Ryan Abernathey

Lamont Doherty Earth Observatory, Columbia University, Palisades.

The most reliable, spatially continuous estimates of global surface currents in the ocean come from geostrophic balance applied to the sea surface height (SSH) field observed by altimeters. Geostrophy provides a good approximation of the dynamics of slow large-scale currents (up to the mesoscale), by filtering out fast timescale processes like inertia-gravity waves/ submesoscale currents. However, current generation high resolution numerical model simulations like the MITgcm llc4320 have revealed the presence of an energized submesoscale with high frequency waves/ tides. These high frequency unbalanced motions are likely to alias the estimation of surface currents from low temporal sampling in current generation of satellite altimeters as well as the upcoming Surface Water and Ocean Topography (SWOT) mission. In this study, we employ machine learning (ML) algorithms of different levels of complexity, starting with a simple linear regression model, all the way up to convolutional neural networks, to estimate surface currents from quantities directly observable by satellites, like SSH, wind, and temperature. We train our ML models with data from available primitive equation ocean GCM simulation outputs of the globe and test the prediction from the ML models against the GCM output for a period different from the training period. Physical insight is provided to the ML models in the form of information about the grid and the neighboring points as a stencil around each point. Since geostrophy relies on non-linear combination of spatial gradients, and the Coriolis parameter (f), linear regression is ineffective at predicting velocities better than geostrophy beyond localized regions with small variation of f or little mesoscale activity. This score is shown to improve with learning algorithms of higher complexity. We describe a relatively shallow neural network which is able to predict surface currents with equal skill as the deterministic geostrophy + Ekman approach. This lays the ground for future work which may go beyond these assumptions.

47. Decadal variability of the Kuroshio Extension: The response of the jet to increased model resolution

Guisy Fedele, A. Bellucci, S. Masina, S. Pierini
Università di Venezia
The Kuroshio Extension (KE) is the eastward-flowing, free, inertial meandering jet formed by the confluence of the Kuroshio and Oyashio western boundary currents. The KE jet is known for its low-frequency variability (LFV) which connects a zonally elongated, fairly stable and energetic meandering jet (elongated state) and a much weaker, highly variable and convoluted jet with a reduced zonal penetration (contracted state). The LFV of the KE are therefore often referred to as being bimodal (Qiu, 2002). The nature of this variability is still under debate; some authors suggest that non-linear internal oceanic mechanisms can play a fundamental role in the phenomenon (Pierini 2006) but there is also evidence from the observations that the KE LFV is connected with changes in atmospheric patterns of variability as the Aleutian Low and the North Pacific Oscillation (Nathan J. and R. Hare, 2002; Qiu B., 2003; L. Ceballos et al, 2009; S. Pierini, 2014; M. Newman et al, 2016). The role of the atmosphere and of the air-sea feedbacks on the KE LFV have been investigated in this work by taking advantage of two coupled-model configurations in the HighResMIP (Haarsma et al., 2016) multi-model ensemble of present-climate simulations, performed under the framework of the H2020 PRIMAVERA Project. The aim of this work is to assess the impact of the coupling between an ocean model and an atmospheric model at different resolutions on the variability of the jet and explore the role of the ocean weather (mesoscale oceanic eddies) in modulating the airsea interactions (as Bishop et al. 2017).

48. The role of atmospheric variability on modulating melt rates in the Filchner Ice Shelf System

Christopher Bull
BAS, UK
The Filchner Ice Shelf System located at the southern boundary of the Weddell sea is the largest body of floating ice in the world, it is fed by four ice streams which have a combined discharge of over 100 Gtons yr^{-1} or approximately 19% of the Antarctic continent. In the future the FISS system then, has the potential to be a major component of Antarctica’s contribution to sea level rise. Work by *Hellmer et al.* (2012; 2017) suggests that the intrusion of warm circumpolar deep water could lead to dramatic, irreversible changes for the ice shelf system in the future, first-order questions remain however, as to the present day factors influencing FISS’ melt rates on inter-annual timescales. Recent in-situ moorings and a seismic survey (e.g. (Rosier et al., 2018)) by the British Antarctic Survey offer an unprecedented opportunity to improve and evaluate numerical simulations of the region. Here, using eddy-permitting NEMO ocean model simulations, we focus on understanding the large-scale ocean and atmospheric circulation patterns that influence melt rates over the re-analysis period. Additional simulations highlight the importance of model settings and ice shelf cavity geometry to melt rates in the Filchner Ice Shelf system. The eddy-permitting results presented shed light on the historical context of the BAS S03/S05 in-situ mooring observations.

49. Global eddying ocean forced by JRA55-do

Dorotea Iovino
CMCC Bologna, Italy

Numerical modeling is an essential tool to represent and understand the climate system, whereof the ocean is a key component. The enhanced realism in representing ocean processes, partially due to increased grid resolution and improved atmospheric forcing, has made the assessment of fidelity of ocean simulations more meaningful and rigorous. It is fundamental to perform simulations in which much of the ocean variability is resolved, and the full dynamics and life cycle of baroclinic eddies are realistically represented.

An advanced numerical approach is presented to characterize mesoscale dynamics in a long-term simulation of the global ocean domain. The GLOB16 configuration, based on state-of-the-art NEMO framework, having 1/16º horizontal resolution at the Equator (increasing up to ~3 km at high latitudes), is used to perform a long hindcast simulation. The experiment design follows a well-established protocol in the ocean modeling community, proposed by the CLIVAR Working Group on Ocean Model Development that consists in simulating repeating-cycles of the atmospheric forcing dataset. The JRA55-do atmospheric forcing is used over the period 1975 to 2017. This numerical exercise is appropriate for studying the dynamics of the 3D ocean circulation on short timescales, but also to investigate the long-term changes in mesoscale activity. Based on the first-cycle results, analysis of the role of mesoscale features in governing the representation of the ocean mean state and ocean variability is presented.

50. GCOAST Model System: coupling of ocean and atmosphere through a dynamic wave interface

Joanna Staneva, Corinna Schrum and GCOAST team
Institute for Coastal Research, HZG, Geesthacht. Contact: Joanna.Staneva@hzg.de

We focus on the evolution of freshwater exchange and water masses process in the Labrador Sea and environs. Using a 1/12 degree Arctic and North Atlantic configurations as well as AGRIF nests at 1/12 degree around the Canadian Arctic, and 1/60 degree in the Labrador Sea, we look at freshwater exchange into the interior of the basin, the impact on mixed layer depth and water formation, and links to the AMOC. The role of melt from the Greenland Ice Sheet is considered, both liquid and solid form. We also examine the role resolution plays in permitting warm waters to reach Greenland and the Canadian Arctic. Experiments using the biogeochemical model BLING examine the importance of freshwater exchange on oxygen and carbon evolution in this region.

51. Sensitivity of the ocean & sea-ice to the choice of the bulk formulae parameterization: a eORCA025-based study

Guillaume Samson (1), Romain Bourdallé-Badie(1) & Laurent Brodeau (2)
(1) Mercator Ocean International, Toulouse, (2) Ocean Next, Grenoble

The AeroBulk package (Brodeau et al. 2017) has been recently introduced in NEMO. It provides 3 new bulk algorithms/parameterizations (ECMWF, COARE 3.0 and 3.5) in addition to the historical NCAR (previously named CORE) parameterization. AeroBulk also introduces some refinements such as the computation of air density and the dependence of surface specific humidity at saturation (qsat) on sea-level pressure. To assess the response of the ocean and sea-ice to the choice of the bulk algorithm used, a set of sensitivity eORCA025 experiments is performed over a five-year period (2013-2017). Firstly, we show that the 3 new bulk algorithms produce similar oceanic and sea-ice responses with different amplitudes with respect to the

NCAR algorithm: a surface warming at mid and high latitudes, a surface salinification in Artic and a decrease of the global sea-ice extent. This general behaviour can be explained by NCAR transfer coefficients atypical values in moderate and strong wind regimes. Thereby, NCAR algorithm produces a weaker wind stress and stronger evaporation with respect to other algorithms. Secondly, we focus on two enhancements introduced by AeroBulk (more accurate estimation of qsat and air density) and show that they have a significant impact on both the ocean properties and the sea-ice extent. The new qsat formulation produces a significant cooling and salinification of the surface in the Tropics by limiting the evaporation. The use of more accurate air density tends to warm the Tropics, increase the salinity in the Arctic and decrease the sea-ice extent in the Antarctic. The physical processes related to these changes will be detailed.