Report of the DRAKKAR Workshop
Online, 18-20 January 2021

[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).

1. Objectives and organization of the online meeting

Due to the pandemic, the DRAKKAR workshop has been held online for the first time. The event was a success: 113 registered participants (more than for any "on site" DRAKKAR workshop); at least 60-80 participants present at any time during the three half-days of meeting.

The overall objective was to review the scientific and technical progress achieved with the DRAKKAR hierarchy of model configurations based on the NEMO platform, identify strengths and weaknesses of these models, and discuss key model improvements and new developments that are needed for the future. Lively discussions are the hallmark of DRAKKAR workshops, and the first motivation for most participants. For this reason, more than 50% of the time has been devoted to discussion sessions, adapted to the online format.

The abstracts submitted have been organized in three science sessions (section 2)

1. High resolution and climate NEMO simulations: strategies and results
2. High latitude regions and southern hemisphere dynamics
3. Modelling issues: parametrizations and numerics

Presentations have been made available to all participants on the web site, before the meeting, and only summaries (one or two slides) have been shown by the authors during the session. This has allowed plenty of interaction with the audience.

Following a survey of the participants in December 2020, 8 discussion topics have been selected (section 3):

1. Representation of topography the bottom boundary with different vertical coordinate systems and their implications for model fidelity
2. High resolution North Atlantic and Arctic modelling
3. Future ensemble strategies for high resolution ocean simulations
4. Submesoscale permitting simulations and their assessment by observations
5. Progress in eddy parameterizations, scale aware parameterizations
6. Analysis of high resolution simulations: challenges and solutions (PANGEO, etc)
7. Modelling the Southern Ocean and ACC dynamics
8. Refining the plans for the adoption and the testing of NEMO 4.2_RC by the DRAKKAR Community

These discussions were prepared before the workshop by two or three discussion chairs. During discussion times, there were two discussions in parallel in two virtual rooms. A conclusion of each has been presented during the final plenary session of the workshop.

The meeting has been held on the gather.town platform and organized technically by the Virtual Chair company (www.virtualchair.net). All participants have enjoyed a rich and fun experience on this platform which was well suited for the DRAKKAR community.

The list of participants is included in this report (annex 1). Presentations and abstracts of the contributed papers listed in section 2 are available on the workshop web site. Summaries of discussions are presented in section 3, and detailed reports of some discussions are included in annex 2.

2. Contributed papers

2.1. High resolution and climate NEMO simulations: strategies and results

- Adrian New: The Westward Spreading of Labrador Slope Water and its Interaction with the Gulf Stream.
- Dmitry Sidorenko: AMOC, Water Mass Transformations, and Their Responses to Changing Resolution in the Finite-VolumE Sea Ice-Ocean Model.
- Mike Bell: Net surface heat fluxes and meridional circulations
- Zeliang Wang: Variations of AMOC from a high resolution North Atlantic.
- Julio Sheinbaum: High Resolution (1km) modelling of the Gulf of Mexico with NEMO.
- Patrick Wagner: Air-sea buoyancy forcing of interannual sea level variability in the tropical Pacific.
- Amber Holdsworth: High resolution climate projections for the Northeastern Pacific Canadian Ocean ecosystem model.
- Anne Marie Treguier: Variability of the mixed layer in the north Atlantic in HighResMIP NEMO simulations.
- Roman Sedakov: Study of water exchange in Kerch strait using NEMO model of Black Sea
- Julie Deshayes: On the importance of tuning ocean configurations for climate simulations

2.2. High latitude regions and southern hemisphere dynamics

- Guillaume Boutin: A new coupled model to shed light on sea ice-ocean interaction
- Jean Sterlin: Role of variable form drag coefficients over sea ice for the ocean surface layer in polar regions
- Paul Myers: High Resolution Modelling of the Labrador Sea and Arctic.
- Polina Verezemskaya: Setting the regional model for the Subpolar Northern Atlantic, implementation of new parameterizations and vertical coordinate to the realistic model based on NEMO4, forcing function and interaction, model dynamics
- Youyu Lu: Research analysis with the 1/4° NEMO model covering three oceans around Canada
- Guillian Van Achter: Landfast sea ice in the Totten Glacier region in East Antarctica.
- Pierre-Vincent Huot: Modelling small scale air-sea-ice interactions in East Antarctica.
- Erik Behrens: What drive changes in the Subtropical Front around New Zealand on interannual time scales.
- Patrick Hyder: Represenation of the Southern Ocean & ACC in HadGEM3.
- Torge Martin: The ACC at Drake Passage and its representation in a hierarchy of NEMO-based climate models.

2.3. Modelling issues: parametrizations and numerics

- Amy Young: Exploring horizontal pressure gradient (HPG) schemes for general vertical coordinates.
- Dave Storkey: Formulation of the Coriolis term and bathymetric steering in z-level models
- Mattia Almansi: Mesoscale features dominating the Denmark Strait overflow and our plan to improve the representation of overflows in global models
- Nicolas Gonzalez: Toward a parameterization of internal tidal mixing in the Mediterranean Sea.
- Alex Megann: The sensitivity of numerical mixing in NEMO to forcing choices
- Hervé Giordani: Eddy-Diffusivity Mass-Flux Parameterization: A new Approach to unify Diffusion and Convection in Ocean Models.
- Robin Waldman: On the barotropic vorticity balance in the NEMO model
- Houssam Yassin: Are the Baroclinic Modes Incomplete? On the Normal Modes of Quasigeostrophic Theory.
- Takaya Uchida: Towards a potential vorticity based mesoscale closure scheme.
- Quentin Jamet: Diagnostic package for analyses of kinetic energy budget of the Gulf Stream in presence of submesoscale dynamics.

3. Summary of discussions

3.1. Representation of topography the bottom boundary with different vertical coordinate systems and their implications for model fidelity

Chairs: Pat Hyder, Jerome Chanut & Amy Young

Discussion- Towards Improved and More Traceable Dynamics

- We tend to think a lot about the surface boundary layer, in part due to heat fluxes, but far less about the bed boundary layer, which had a profound impact on flows but is poorly represented in our models, particularly with z partial step coordinates.
- Urgent need through suitable diagnostic outputs to better understand the role of bottom forces – bed stress and bottom pressure forces, and their torques (BPT) accumulated impact (form stress) & internal stresses including the associated generation of internal waves.
- Also the role of these forces in the barotropic and baroclinic vorticity and directional component balances and their link to large-scale emergent properties like the ACC, gyre strengths, etc.
- In general because eddies are more barotropic, they feel the bed forces more than mean flows which often tend to be surface intensified so eddy representation matters to the fidelity of the impacts of bottom processes.
- Note: it was suggested to talk to Eric Chassignet.

More technical points

- Given huge sensitivity, treatment of topography is rather adhoc and understanding of the role of roughness and right level of smoothing is very limited.
- Lots of useful idealised and realistic studies over the years.
- Hard to separate real impacts of bottom roughness from impacts of errors in numerical representation.

- Are we just putting in spurious noise with roughness so getting improvement for wrong reason? We hugely need a theory constraint to test our numerics – is there potential to use time mean vertical velocities near the bed compared to BPT?
- Filtering - we currently use 3 passes of a Shapiro Filter but MOM use no smoothing with ALE or z-ps (?) and Bernard also mentioned the dangers of smoothing, in part due to impacts on straits and channels, so perhaps we should go with simple area meaning of raw data only smoothing where there are known issues.
- The importance of testing better numerics was mentioned.
- Collaborative effort drawing on the community was felt to be useful and the idea of a follow up workshop in the spring was briefly discussed.

3.2. High resolution North Atlantic and Arctic modelling

Chairs: Paul Myers, Camille Lique

Topics discussed are the following :

What high resolution Arctic and Atlantic modelling studies are ongoing?

Is 1/60th a good resolution? Good enough. Or should we go to even higher resolution?
No consensus, but 1/60th was considered good, especially given costs

What vertical resolution to go with very high horizontal resolution?

Some studies suggested very high vertical resolution is not necessarily better
Some groups did well with low vertical resolution
No clear idea – generally groups go with what works for them

Length of run – cost versus need for inter-annual studies?

Most such runs are short, given cost and thus focused on process studies
Longer studies needed smaller domains (AGRIF but that has limitations)

How to determine parameters and how to force?

Forcing includes rivers, ice sheets and icebergs.

Discussion on how to evaluate model simulations

What type of statistics and data might be available and how it could then be used

What about inter-comparison of such experiments

A key role of such models was felt to be understanding processes so that they can be parameterized in coarser resolution climate models

Sea-Ice models: Need to explore more diversity in term of model dynamics/thermodynamics

3.3. Future ensemble strategies for high resolution ocean simulations

Chairs: Thierry Penduff and Laurent Terray

The objective of ensembles is to simulate the sensitivity of model solutions to uncertainties
There are different strategies, e.g.:

- SMILES (Single-Model initial-condition large ensembles): Lorenz models, dynamical Systems Theory
- PPEs (Perturbed Physics Ensembles): Barely any theory

One may distinguish 2 types of ensembles:

- Ensembles on purpose: C/O-MIP, OCCIPUT
- Ensembles of opportunity: DRAKKAR

Example of an oceanic SMILE (on purpose): OCCIPUT (50 members, global NEMO 1/4°, 1960-2015)

Main discussion topics

1. Number of ensemble members?

- Should be large enough to capture bi/multi-modal E-PDFs, or extremes (N>50?)
- But limited by CPU resources (we often have 10-50 ensemble members, up to 200)
- An a priori answer may be given by e.g. latin hypercubes (but theoretical N is massive)
- An a posteriori answer can be estimated when the ensemble is available (e.g. Milinski et al 2019, Wills et al 2020)

2 - Use of atmospherically-forced oceanic ensembles (e.g. OCCIPUT)

- mandatory to disentangle atmospherically-forced variability (AFV) & Chaotic intrinsic variability (CIV)
- new questions & paradigms emerge from such runs, which stimulates the development of new metrics
- However, prescribing forcing distorts ocean physics
- What is impact of CIV (which strongly impacts SST and Heat Content) on atmosphere and climate ? The strategy to address this important question is not clear yet.

3 - How to exploit the DRAKKAR database (PPE of opportunity) to rationalize the calibration of NEMO?

- Use of history matching for automatic tuning (J. Deshayes' talk, ongoing research at MetOffice, Williamson et al 2017)
- Apply pattern recognition, Signal/Noise maximizing EOFs (Wills et al 2020), classifiers (e.g. Maze et al 2017) to link parameters and model behavior
- Build an emulator of model sensitivities (—> optimize parameters of CNRM-CM6 atm. model. PhD Saloua Peatier)

Some perspectives and challenges

1 - Ocean heat content low-frequency large-scale chaotic intrinsic variability (CIV):

- Impact on atmosphere? Forcing atmospheric ensembles with OCCIPUT SST realizations (Thierry Penduff). On regional domains? At which resolution? Collaborations are welcome.
- Impact on climate? How to disentangle CIV from atmospherically-forced variability and from coupled modes in ocean-atmosphere simulations? Can climate ensemble modelers help progress on this question?

2 - Replacing the temporal by the **ensemble dimension in turbulent diagnostics**

- More consistent with Reynolds decomposition principles
- Access the temporal changes of eddy effects e.g. rectification, eddy fluxes, SGS, etc (See T. Uchida's presentation)
- LES or QG ensembles CAN help progressing on this!

3 - Optimizing the choice of NEMO parameters from the **DRAKKAR "ensemble" archive**

- DRAKKAR database = ensemble of opportunity. It documents combined NEMO sensitivities. Can we (and how to) extract & rationalize this information to assess individual sensitivities to parameters?
- 1) Pick simple (1D/2D) model fields 2) Use classification tools to disentangle sensitivities
- Can climate ensembles help progressing on this?

4 - Using ensemble runs to **attenuate CIV** in **modeled and observational datasets**

- Sea level anomaly (SLA) example: OCCIPUT outputs —> design a filter to estimate E-mean (AFV) from 1 member (AFV+CIV). Applied on SLA —> successfully works with AVISO (Close et al, 2020).
- Which other observed variables would deserve this kind of study? Can we separate AFV/CIV in such variables as well? Some kind of separability (e.g spectral) between forced and intrinsic helps!

5 - **Non-Gaussian behaviors and metrics**, link with Dynamical Systems Theory

- Ensemble-mean/Ensemble-std fully describe Gaussian Ensemble-PDFs. Entropy/information metrics are less restricted,

- and more consistent with DST (where no AFV/CIV split is allowed, and thus not made)
- Climate/idealized ensembles CAN help in progressing on this!
- Dynamics of atmospherically-modulated CIV?
- Oceanic predictability in the eddying regime

6 - Maximizing the benefits of ensemble ocean runs while **minimizing CPU**

- Compare benefits of resolution vs ensemble size from existing ensembles & runs
- Parametrize CIV in coarse ocean/climate models? Not much has been done on this.
- Pure CIV studies do not require ensembles: cheaper climatological runs may be sufficient…

3.4. Submesoscale permitting simulations and their assessment by observations

Chairs: Takaya Uchida and Stephen Griffies

Basic question: how to evaluate submesoscale eddy permitting/resolving simulations? Guidance from eNatL60 simulations from J. Le Sommer and co. has been presented to provoke discussion.

- Tides: Well defined forcing with mature tide models for direct comparisons of phase lines (patterns) and frequency power spectra. Tides also provide a constraint on bottom dissipation (e.g., Arbic's work).
- Horizontal surface buoyancy gradient: helps to identify regions prone to frontogenesis (and mixed-layer instability?).
- Shape of probability distribution: In addition to the mean and std, skewness and kurtosis could provide information regarding the underlying physics (Adam Blaker).
- High-res air-sea fluxes: probably need a coupled run (Polina Verezemskaya)
- Wave-number spectra with direct comparison to along-track satellite surface height measurements. Even with questions of windowing, it seems likely that this sort of model-obs/model-model comparison will remain common into the future in order to extract common/robust signals. (J. Le Sommer)
- This in turn can help design in-situ observation campaigns (Kyla Drushka)
- Filtering as per H. Aluie et al (2018, JPO): This approach offers means to map turbulent cascade even near boundaries. It avoids problems with windowing found with wavenumber spectra. Caveat: it is useful to have data on a uniform grid to reduce time cost of the method. (Rene Schubert) Maybe we can package this for future users. (J. Le Sommer)
- Wave-number spectra without windowing: suggestions that we can get interesting physical information from wavenumber spectra even if we do not window, and in turn this approach avoids the questions about windowing. So what are the reasons against it? Ultimately, we are interested in understanding the predictable part of the eddy field, and this approach might add insights. (Bill Dewar)
- SWOT cal-val phase: Will be quite a rich dataset to compare models and high sampling obs. eNATL60 is gearing up for the measurements in 2022.
- Lagrangian diagnostics: Can one learn about eddy energetics and life-cycles by following an eddy and performing energy cycle analysis in the moving eddy frame? (Anne Marie Treguier)
- 3D information: vertical buoyancy flux diagnostics and the role of eddy variability in affecting this flux (Takaya Uchida will consider as part of a 5-model comparison project; https://github.com/roxyboy/SWOT-AdAC-ocean-model-intercomparison). Colleagues having model outputs to contribute to the project are invited to reach out to Takaya.

3.5. Progress in eddy parameterizations, scale aware parameterizations

Chair: Dave Storkey

Ongoing work on eddy parametrisations in NEMO:

- Papers by Pavel Perezhogin on implementation of backscatter (Jansen et al scheme?) in NEMO 3.6.
- UK working group just starting to coordinate UK work on backscatter in NEMO (Dave Storkey).
- Implementation of GEOMETRIC scheme in NEMO (Julian Mak).
- Work at IPSL, Paris: Gent-McWilliams in ¼ deg model and machine-learning parametrisations (Julie Deshayes).
- Work on deterministic and stochastic backscatter schemes at GEOMAR (Joakim Kjellsson)

Work on parametrizations in the wider community:

- "Ocean Transport and Eddy Energy" Climate Process Team led by Laure Zanna in US. (an open meeting taking place at the end of January was announced: https://ocean-eddy-cpt.github.io/)
- TRR181: "Energy Transfers in Atmosphere and Ocean" group led by Carsten Eden in Germany
- Uchida et al (see Drakkar talk).
- Robin Waldman (CNRM)

In general, it would be good to have standardised testing protocols for backscatter schemes

Discussion on isopycnal diffusion:

- Bernard Barnier working on isopycnal diffusion in s-coordinates in NEMO. Finds the fields very noisy (as do others), and has issues with steep isopycnal slopes.
- Gurvan Madec commented that noisy tracer fields partly due to viscosity being set too low.
- Gurvan and Alex Megann have both done extensive sensitivity tests with viscosity.
- A. Shao is working on isoneutral diffusion in the context of general vertical coordinates. (see JAMES 2020 : https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2019MS001992)

3.6. Analysis of high resolution simulations: challenges and solutions (PANGEO, etc)

Chair: Willi Rath

Key questions:

Where / How can we store data for easy collaboration?

→ platforms (e.g., http://2i2c.org/)

How to store data in an HPC and cloud compatible file format?

→ Zarr (object-storage ready, will be new netCDF backend)

→ Object storage on HPC?

How to debug / profile distributed computing applications?

How can we enable non-modelling experts to work with our data?

→ platforms / tutorials?

Necessary (coordinated) actions

Towards community based tools.
→ Easy reference for standard diagnostics?
→ Formalising best practices?
Towards community-specific docs.
→ Real-world examples beyond the simple documented applications
→ Emphasize best practices from technical point of view
Towards shared data / computing platforms.
→ Data analysis for modelling experts.
→ Data / tool / result sharing with other experts.
→ Providing data and tools for non-experts.
→ Easy interaction with tech experts.
Towards HPC / cloud interoperability.
→ Get rid of the INODE problem via object storage @HPC?
→ (Jupyter-based) interactive to HPC?

3.7. Modelling the Southern Ocean and ACC dynamics

Chairs: Lavinia Patara and Torge Martin

Main topics of the discussion were (see annex 2 for more details):

1 - Interaction of ACC and high-latitude Southern Ocean (SO)

- models resolve fronts in ACC better, jet dynamics need investigation, are retroflections/countercurrents real? on which time/space scales?
- models also now resolve high latitude SO better, shelf is new focus region, slope current dynamics become important
- bottom interaction (roughness) matters, high-res. topography (islands) needed

2 - Ice-ocean interaction:

- ocean dynamics require ice shelf and iceberg processes to improve
- how Antarctic sea ice is different from Arctic, adjust model tuning
- land-fast ice, grounded icebergs as anchors/shields, important for polynyas
- AGRIF not up to speed with ice developments (cavities, bergs, ...), thus more regional model configurations

3 - Biases:

- how to deal with coastal freshwater, causes major dynamical issues
- which biases should be tackled, which matter most for global climate (change)?
- how do we share our knowledge, how do we join forces?

3.8. Refining the plans for adoption and testing of NEMO 4.2_RC by the DRAKKAR Community

Chairs: R. Bourdalle-Badie, M. Scheinert, J. Le Sommer

Objectives of the discussion session

- Inform DRAKKAR groups about the schedule of the upcoming NEMO release
- Describe the validation process for NEMO v4.2 set up by NEMO ST & IMMERSE
- Share plans for the adoption of NEMO v4.2 amongst DRAKKAR groups
- Discuss how to best exchange information on the validation of new NEMO code

Format and approach of the discussion

Information on NEMO v4.2 has been circulated before the discussion:

- Timeline and new features of the upcoming NEMO release

- Idealized test cases in NEMO
- Validation based on realistic configurations in IMMERSE
- Sharing NEMO configurations with SIMSAR

A survey has been carried out to share plans on the adoption of NEMO v4.2

Main conclusions and decisions

based on the input by ~10 groups in the DRAKKAR community + discussions

- All the groups are interested in adopting/testing NEMO v4.2 in 2021
- and intend to perform comparisons with configs based on NEMO 3.6 (or 4.0.3)
- A broad interest in the new code features (icebergs, vertical physics, ABL-1D)
- Most groups will wait until the official release of NEMO v4.2 (mid 2021)
- Several groups would be happy to test SIMSAR sharing protocol in 2021
- Exchanging info. amongst users through dedicated meetings would help
- The monthly NEMO users discussion in Canada (virtual, open to all) could be used for this.
- Organizing a discussion alongside an IMMERSE workshop in Oct. 2021 is also a possibility

ANNEX 1: List of participants

Registered Participants (113)

DRAKKAR IRN partners (France, UK, Germany): 52

IGE - Grenoble (12): Bernard Barnier, Pierre Brasseur, Pedro Colombo, Bruno Deremble, Jean Marc Molines, Thierry Penduff, Quentin Jamet, Takaya Ushida, Julien Le Sommer, Pierre Mathiot, Pierre Rampal, Nicolas Jourdain,

GEOMAR - Kiel (18): Arne Biastoch, Claus Böning, Jan Klaus Rieck, Franziska Schwarzkopf, Joakim Kjellsson, Lucienne Micallef, Siren Rühs, Markus Scheinert, Klaus Getzlaff, Wonsun Park, Willi Rath, Christina Schmidt, Tobias Schulzki, Rene Schubert, Torge Martin, Lavinia Patara, Patrick Wagner, Mathias Zeller

NOC - Southampton (5): Mattia Almansi, James Harle, Adrian New, Adam Blaker, Alex Megann

Met Office Hadley Center - Exeter: (7): Pat Hyder, Dave Storkey, Mike Bell, Diego Bruciaferri, Helen Hewitt, Catherine Guiavarc'h, Amy Young

LOPS - Brest (6): Anne-Marie Treguier, Claude Talandier, Camille Lique, Angelina Cassianides, Thierry Huck, Guillaume Maze

LOCEAN - Paris (5): Anne-Cecile Blaizot, Gurvan Madec, Julie Deshayes, Ute Hausmann, Clément Rousset

Other French laboratories (13)

LEGOS - Toulouse (4): Marco Larrañaga, Manon Gévaudan

CNRM-CERFACS Toulouse (4): Nicolas Gonzalez, Robin Waldman, Herve Giordani, Laurent Terray

MERCATOR Ocean Intl - Toulouse (4): Clément Bricaud, Jerome Chanut, Romain Bourdalle-Badie, Guillaume Samson

INRIA Grenoble (1): Florian Lemarié

Europe & Russia (27)

UCL - Louvain la Neuve (6), Jean Sterlin, Pierre Vincent Huot, Deborah Verfaillie, Guillian Van Achter, Charles Pelletier, Tim Orval

University of Northumbria (1): Christopher Bull

University of East Anglia (1): Dave Stevens

University of Utrecht (1): Erwin Lambert

AWI Bremerhaven (5): Nikolai Koldunov, Sergey Danilov, Qiang Wang, Dmitry Sidorenko, Patrick Scholz

University of Gothenburg - Sweden (2): Romain Caneill, Birte Gülk

CMCC – Italy (2): Dorotea Iovino, Julia Selivanova

IORAS Moscow (3): Polina Verezemskaya, Roman Sedakov, Sergey Gulev

ECMWF - Reading (4) : Chris Roberts, Niels Wedi, Kristian Mogensen, Jean Bidlot

NERSC - Bergen (3): Guillaume Boutin, Einar Olason, Heather Regan

America & New Zealand (21)

GFDL Princeton (2): Stephen Griffies, Houssam Yassin

University of Alberta - Edmonton (3): Clark Penelly, Paul Myers, Juliana Marini Marson,

University of Calgary (1): Chengzhu Xu

Florida State University/IGE Grenoble (1): William Dewar

CICESE - Mexico (1): Julio Steinbaum

DFO-MPO – Environnement Canada (10): Frederic Dupont, Youyu Lu, Michael Dunphy, Neil Swart, Amber Holdsworth, Zeliang Wang, Simon St Onge Drouin, François Roy, Stephanne Taylor, Li Zhai

University McGill Canada (1): Carolina Dufour

NIWA - New Zealand (1): Eric Behrens

Annex 2 : detailed reports of discussions

Session A1 –Representation of topography the bottom boundary with different vertical coordinate systems and their implications for model fidelity
Chairs: Pat Hyder, Jerome Chanut & Amy Young

In Attendance (~47 participants)
Mattio Almansi, Bernard Barnier, Erik Behrens, Mike Bell, Sarah Berthet, Adam Blaker, Claus Böning, Romain Bourdallé-Badie, Diego Bruciaferri, Deremble Bruno, Christopher Bull, Angelina Cassianides, **Jerome Chanut**, Sergey Danilov, Julia Dehayes, Manon Gévaudan, Nicolas Gonzalez, Stephen Griffies, Birte Gülk, James Harle, Helene Hewitt, **Patrick Hyder**, Erwin Lambert, Youyo Lu, Gurvan Madec, Pierre Mathiot, Alex Megann, Kristian Mogensen, Antoine-Alexis Nasser, Adrian New, Thierry Penduff, Willi Rath, Francois Roy, Christina Schmidt, Patrick Scholz, René Schubert, Franziska Schwarzkopf, Julio Sheinbaum, Dmitry Sidorenko, David Stevens, Dave Storkey, Laurent Terray, Takaya Uchida, Polina Verezemskaya, Robin Waldman, Houssam Yassin, Amy Young.

Overarching Themes/questions (see breakout introduction slides):

- *Large biases in NEMO & other ocean models exist associated to the definition of topography*
- *Some sensitivities to topographic roughness are expected from theory for the real world*
- *Some may be due to numeric representation errors of near-bed processes, which depend considerably on vertical coordinate choices.*
- *In NEMO there are substantial resolution & topographic roughness dependent Southern Ocean coupled model biases.*
- *For example, the persistent problem of downward ACC drift in the standard model (with over-smooth topography) is reversed with a considerable upward ACC simply by using rougher topography (although we do not know for sure yet that this is for the right reasons as it could be via spurious noise &/or error cancellation with eddy processes).*
- *Aside: If there is sufficient interest, following DRAKKAR, we propose to hold a virtual workshop, over ~4 half days, to (a) review the state of knowledge and plans from wider community and b) to investigate medium and longer-term options within the NEMO community.*

Overview Summary Discussion Notes (taken from report back slides – add link to slides?):

a) Discussion- Towards Improved and More Traceable Dynamics

- We tend to think a lot about the surface boundary layer, in part due to heat fluxes, but far less about the bed boundary layer, which had a profound impact on flows but is poorly represented in out models, particularly with z partial step coordinates.
- Urgent need through suitable diagnostic outputs to better understand the role of bottom forces – bed stress and bottom pressure forces, and their torques (BPT) accumulated impact (form stress) & internal stresses including the associated generation of internal waves.

- Also the role of these forces in the barotropic and baroclinic vorticity and directional component balances and their link to largescale emergent properties like the ACC, gyre strengths, etc.
- In general because eddies are more barotropic, they feel the bed forces more than mean flows which often tend to be surface intensified so eddy representation matters to the fidelity of the impacts of bottom processes.
- (Talk to Eric Chassingnet was suggested)

b) More technical points

- Given huge sensitivity, treatment of topography is rather adhoc and understanding of the role of roughness and right level of smoothing is very limited.
- Lots of useful idealised and realistic studies over the years.
- Hard to separate real impacts of bottom roughness from impacts of errors in numerical representation.
- Are we just putting in spurious noise with roughness so getting improvement for wrong reason? We hugely need a theory constraint to test our numerics – is there potential to use time mean vertical velocities near the bed compared to BPT?
- Filtering - we currently use 3 passes of a Shapiro Filter but MOM use no smoothing with ALE or z-ps (?) and Bernard also mentioned the dangers of smoothing, in part due to impacts on straits and channels, so perhaps we should go with simple area meaning of raw data only smoothing where there are known issues.
- The importance of testing better numerics was mentioned.
- Collaborative effort drawing on the community was felt to be useful and the idea of a follow up workshop in the spring was briefly discussed.

Detailed Notes (drafted by Amy Young)

Introductory material: **Pat Hyder** *[Presentation]*

Presentation By Patrick Hyder (Available online)

- Focus on topographic roughness in ACC context.
- Goals in NEMO
    1. Immediate – some blending of LEGO topography
    2. Medium Term – regeneration of topography at the different resolutions
    3. Medium Term – terrain following coordinates?
    4. Longer Term – optimal mixed-coordinate configurations

Discussion Summary

- There should be an action as a community to ensure diagnostics relating to bottom physics/topography are be generated and used as routinely as surface diagnostics such as wind stress curl (form stress, topographic curl, bottom pressure torque etc). Furthermore, we should combine looking at the emergent properties (e.g. ACC) with analysing the underlying processes (e.g. bottom pressure torque etc) – this requires routine output of bottom/topography-related diagnostics. (SGriffies and others)

- There was a call for a systematic study looking at the number of grid points per resolved scale (giving us a better understanding of what is noise and what is physics) (TPenduff)
- Treatment of bathymetry: Current ORCA12 bathymetry has no smoothing, the ORCA025 applies 3 passes of the Shapiro filter, nothing complex. There was a general feeling here that, while treatment of the bathymetry is straighforward, keeping track of what has been changed is the hard part – smoothing always requires manual editing of the resulting bathymetry. Furthermore, even when simply appling a Shapiro filter, it's important to bear in mind what scales you might be filtering out. BBarnier was against local topographic smoothing. (RBourdallé-Badie, JChanut, BBarnier)
- Some approached the discussion regarding the impact of topography on the flow from the physics point of view, others from the numerics.
    - Physics: CBöning would like to see more analysis of the physics – in particular, one of the key issues is how topography interacts with eddys – topography has a strong impact on the vertical structure of the eddy-field. The North Atlantic could form the basis of a case study here – high resolution models show the eddy-field to be too barotropic in this region. <Comment from Mike here regarding the barotropic nature of the eddy-field>
    - Numerics: JChanut stressed the importance of improving the numerics. For example, the penalisation technique (See Debrau 2020 for CROCO application) is currently being implemented and we should see results in the next few years.
    - Following on from comments that topographic roughness is effectively a constant forcing of noise, we should try to understand the mechanisms behind the improved results from the LEGO runs. If we're getting better results with "more friction", perhaps we should account for this in a different way e.g. smooth then parameterise this friction rather than doing it with artificial forcing via topographic noise. (DStorkey, GMadec)
- No-one at the session had attempted basin-scale s-coordinate simulations. MOM6 use their hybrid HYCOM grid and SGriffies stressed the benefits of having a model with no side-walls ("ocean has no sides, only a bottom"). However thin the side-wall boudary layer is (e.g. 1/60deg models), it still has an impact. (SGriffies, BBarnier). There's still a question here as to what an isopycnal grid looks like near the bottom, and there was a call for a study on interaction with topography in isopycnal coordinates.

- Ocean is quite behind atmosphere in terms of analysing form drag. There is currently work at Imperial looking at form drag in very high resolution models. (Jchanut, MBell)

Full Discussion

BBarnier – QG models - topography represents constraint on vorticity – so you get a form drag – integrated drag for ACC will be different if you resolve eddies versus if you don't resolve eddies because these will interact with the topography. Interaction between transient and standing eddies are important in setting the strength of the ACC. Running QG models, topographic roughness also impacts baroclinicity of the flow – trapping it near the surface. They would *not* recommend local applications of topographic smoothing. **PHyder** – this suggestion was due to Pat Heimbach's sensitivity study which looked at the impacts of smoothing various locations e.g. the Kerguelan Plateau i.e. P Hyder is not suggesting local treatment as a permanant solution. **BBarnier** - Zika paper – flow is not fully zonal, penisula is also putting drag and constraining the flow.

SGriffies – Point 1) *Proposed potential action as a community to establish better diagnostics*. – wind stress curl is very widely used, but diagnostics such as topographic curl, depth integrated flow should be more routinely used. Point 2) *Combine looking at emergent propoerty (i.e. ACC) with analysing the underlying processes*. (requires the diagnostics e.g. bottom pressure torque from point 1). Notes that this is difficult because form drag is self-referential, it arises from the flow itself, it's not externally imposed. Conclusion: It should be more routine to analyse these diagnostics.

PHyder – Open question on numerical representation of top – what are the contraints on how we can represent the bottom pressure torque etc? Are there useful constraints that can be applied to the model to detect when there are issues such as over-steepness or over roughness?

TPenduff – stresses the importance of *number of grid points per resolved scale*. Threshold on number of gridpoints to represent smallest scales. (BBarnier?) - Did tests in OPA, full-step. Impact of small scale structures was more like a noise related thing – you couldn't find the expected QG results. When you did 10dx (i.e. big smoothing) you found that the QG flow could be found. How far can we go on the smoothing before we get rid of noise and find real results? **TPenduff** - *number of grid points per resolved scale is the important thing here*. **PHyder** – yes, in the past, we've seen ACC get better for the wrong reason. However, eke doesn't go up and, if it was spurious, you would expect it to go up. **TPenduff** – making topography rougher increases dissipation.

MBell – it there more factual information on what kind of smoothing has been done? How much smoothing, what type of smoothing (simple filter or something more), how much relative to the grid scale?

- **RBourdallé-Badie** – ORCA12 bathymetry has no smoothing (v3.6). ORCA025 uses a simple Shapiro filter with 3 passes – nothing complicated from a numerical point of view.

- **PHyder** – Filter's do a good job on the roughness but they also smooth unecessarily. – is there a possibility to do something more locally on steepness? **R**Bourdallé-**Badie** – notes that smoothing can impact e.g. strait depths so requires post-smoothing modifications. **PHyder** – notes that this is an argument *for* local smoothing based on steepness threshold rather than global filter

- **JChanut** – smoothing the bathymetry is one thing, storing the information on what you did is the difficult bit.

JChanut – the numerics also needs to be considered, not just the topography e.g. new work on penalisation methods (Debreu 2020). We do need to work on the numerics, not just the topography – what's Gurvan's thoughts on this?

- **GMadec** – topography represents a constant (because it is constant in time) noise forcing in your solution. Penalisation technique is currently being implemented and studied – will see the results in the next few years (see Laurent's work in CROCO)

- **TPenduff** – Shapiro is both simple and cheap *but* running it multiple times – you need to keep track of what you've filtered out – again stressing the importance of considering grid points per resolved scale.

PHyder – Open question to the room - has anyone run basin-scale s-coordinate simulations?

- **SGriffies** – currently using the hybrid HYCOM coordinate system (they have tried z* all the way through the column but moved to hybrid to reduce spurious mixing). **SGriffies** favourable on ALE coordinate – Ocean has no sides, it only has a bottom. MOM6, bottom is a drag law, even at the shore line. He would really like to have a nuermical phd student to look at sensitivities here

CBöning – stresses that they *would like to see a focus on the physics/mechanisms of what's going on rather than the numerics and concludes that the biggest issue is with the eddying part of the flow*. An increase in roughness in the ACC region increases the energy of the uper level flow which is counter-intuitive – but what you have to understand is that the topography is acting on the bottom of the flow. The topgraphic roughness should remove energy from the eddy-part of the flow rather than the mean part – we need to think about the interaction between the mean and eddy-ing flow. Looking at North Atlantic – it seems to be too barotropic in the highly eddying-results compared to observations. the NA region could form the basis of a study comparing the vertical structure of the (eddying-part) of the flow. They suspect that any change in the topgraphy whill have a strong impact on the vertical structure of the eddying part of the flow. **PHyder** – what about the ORCA025 when you have *partially resolved* eddies? **CBöning** – did some work with Cox on this over the past decades for example, looking at the effect of roughness on an eddying model with 1/3deg resolution In response to PHyder's questions – it doesn't matter. As long as you have an eddying and mean part that you can separate, you can analyse it. Findings were that the eddy-part is more barotropic than the mean-part of the flow. Conclusion is that the biggest issue is with the eddying part of the flow.

- **BBarnier** – fully shares CBöning's explanation. Topographic smoothing is very different in eddying and non-eddying models. The approach for finding a solution will therefore be very different depending on whether you're working with an eddying or non-eddying model.

- **JChanut** notes that having a *tide-resolving* model also makes topography important.

- **BBarnier** also reinforced the point about side-walls in ocean models. Even at 1/60th degree resolution, the side-wall boundary layer will be smaller, but we will still have a problem. Resolution of the bottom Eckmann layer is still an issue. S-coordinates does this better, iso-pycnal coordinates may also be able to do this better but unsure on what iso-pycnal grids look like near the bottom.

TPenduff – is there a good paper on bottom stress, form stress in iso-pycnal coordinates? – i/e/ is there a paper on interactions with topography in iso-pycnal coordinates? There may be papers – Hallberg may be a good person to ask. Eric(?) may hae also done some work on this?
AYoung – how does an isopycnal coordinate look along the bottom layer? Is it a nice smoothly varying, continuous line of cells?

- **SGriffies** response? (Wifi cut out here)
- **TPenduff** - What is physical versus what is numerical is obvious – test cases doing lots of deltax per resolved scale. You will get to noise at some point but it would be good.

BBarnier – Following up on **SGriffies** point regarding the need for better diagnostics. Form stress etc diagnostics are essential – we should have them in most of the runs we do. We need a better understanding of what the form stress should be. We should have an iterative process if we want to be accurate – we currently don't know the stress but it strongly influences the flow above – for a very accurate estimate of the effect, we need an iterative process.
DStorkey – Following on from the comments that it's effectively a constant forcing of noise (Gurvan) maybe we should understand the mechanisms behind the improved results from the LEGO runs. We're getting better results with "more friction". Perhaps we should account for this in a different way e.g. smooth then parameterise this friction rather than doing it with artificial forcing via topographic noise.
JChanut – we are way behind atmospheric community on form drag. **MBell** – actually, this is being investigated at Imperial with very high resolution methods.
MBell – following on from comments about flow being much more barotropic <Mike could probably give a more eloquent summary on this>
PHyder – put out the feelers for a workshop on topography – not much response (From chat, Takaya Uchida indicated interest)
<u>Text copied from the discussion chat</u>
Sheinbaum - FSU found strong sensitivity of the Loop Current to bottom friction in HYCOM
RSchubert – A specific question aside the roughness topic: Does somebody in the room has experience with the ratio of vertical/horizontal resolution on the representation of the overflow in z-coordinate models? **BBarnier** – René, we explore this a little bit in a recent paper of Pedro Colombo (GMD2020) and our conclusion is that, valid for NEMO, there is not clear gain with a very high vertical resolution. Colombo et al 2020.

Session D1: Modelling the Southern Ocean and ACC dynamics

Chairs: Lavinia Patara and Torge Martin

The Southern Ocean discussion group aims at highlighting scientific and technical challenges in Southern Ocean research and modeling, possible ways forward, and future avenues of research which could be expanded in the DRAKKAR community.

Introduction

The Southern Ocean is a key region for the ocean uptake of excess heat and of anthropogenic CO_2, almost half of the ocean uptake of anthropogenic CO2 takes place in the Southern Ocean. The future evolution of the global climate critically depends on how the Southern Ocean will respond to the changes in wind, temperature and Antarctic melt associated with global warming. Ocean and climate models are crucial tools to understand Southern Ocean dynamics, its response to climate change and its connection to heat and carbon uptake. In this discussion group we focused on four topics where great advances have been made but large uncertainties remain: 1) Eddy-rich models, 2) Biases in ocean and climate models, 3) Ocean interaction with sea ice and ice shelves, and 4) Ocean heat and carbon uptake.

1) Eddy-rich models

Introduction: High-resolution modeling is helping us understand key aspects of the Southern Ocean dynamics. A relevant question for instance is the role of standing and transient eddies in compensating the mean/Eulerian MOC. The extent to which eddies can compensate wind-driven increases in the mean MOC is still an open question. Eddy-rich models also provide a more realistic representation of small-scale currents and sometimes “cure” some of the model biases.

Discussion questions:

a) What resolution is "adequate" for which processes?
b) Does increasing the spatial resolution improve the realism of simulations? Advantages / drawbacks?
c) Does enhanced horizontal resolution require increased vertical resolution and improved interaction with topography?
d) Which high-resolution Southern Ocean studies are ongoing? Scope for intercomparison/collaborations?

2) Biases in ocean and climate models

Introduction: Global warming relates to coupled processes and complex feedbacks. Therefore, ocean-only models not fully adequate to study all aspects of global warming and coupled climate models need to be applied to the problem. Such models have more freedom to evolve into their own climate state and are thus prone to biases. How do we make use of the best of both approaches, ocean-only and coupled models?

Discussion questions:

a) Recent improvements and remaining biases
b) Understanding the **causes** and finding **solutions**?
c) Which observations are needed for validation?
d) Should the community share more knowledge of their biases and recipes?

3) Ocean interaction with sea ice and ice shelves

Introduction: Ice-ocean interaction is a key element in watermass transformation in the Southern Ocean, which in turn links to the global overturning circulation. Enhanced ice melt by warm waters reaching the Antarctic shelf is a major factor in Antarctic ice loss and global sea level rise. However, there are still many unknowns and processes are not well represented in models. Eddying simulations of the Southern Ocean high latitudes have recently become feasible due to growth in computer power but need more observational support for validation and also require high-resolution topography. Further, ice-related feedbacks can enhance ocean model biases, e.g. the SST–sea ice–albedo feedback and T_{CDW}–ice-shelf bottom melt.

Discussion questions:

a) Which processes do we neglect and what are the consequences?
b) How to properly simulate both coastal and open ocean polynyas?
c) Are there simple/cheap solutions to adding ice-shelf processes and icebergs to ocean models?
d) Experience with eORCA
e) Joint freshwater experiments?

4) Ocean heat and carbon uptake:

Introduction: The Southern Ocean south of 35°S, even though covering only ~25% of the global ocean, is responsible for approximately 30-40% of the global oceanic uptake of anthropogenic CO_2 and for approximately 75% of the oceanic uptake of the excess heat generated by human activities. Ocean (biogeochemistry) models help unraveling the changing patterns of heat and carbon uptake. Eddy-rich (biogeochemistry) models are increasingly helping to understand the role of mesoscale eddies for heat/carbon uptake.

Discussion questions:

a) Which biases in ocean/climate models are hindering our understanding of changing heat and carbon uptake?
b) Trade-offs between ocean resolution and biogeochemical complexity?
c) How important is a proper representation of ocean-ice interactions?
d) Would you be interested in a model intercomparison on this topic

Discussion

1) Interaction of ACC and high-latitude Southern Ocean

- Bottom interaction (roughness) matters, high-res. topography (islands) needed. How good is the topography in observations?

    - Pat Hyder finds that higher resolution models become more sensitive to e.g. choices regarding topography.
- Until a decade ago ACC and high-latitude were somewhat separated topics. Now we see the importance of understanding the high-latitude processes (slope current, interaction with ice cavities, icebergs) for getting the ACC right.
    - The Weddell Gyre is suggested to be a key element for the regional dynamics connecting the slope current on its sothern and the ACC on its northern flank.
    - David Stevens: models with a very weak ACC have a depressed thermocline which inhibit the transport of CDW onto the shelf (as observed).
- Are retroflections/countercurrents in the ACC/Drake Passage real? On which time/space scales?
    - Models increasingly resolves fronts in ACC and interesting jet dynamics emerge which needs further investigation. What are the dynamics of the jet currents? (Steve Griffies)
    - Pat: spurious retroflections in decadal averages of model simulations. But you can see these retroflections are also there in reality but they move or are more intermittent.
    - David Stevens: A number of cruises have done quite fine sections up the slope and not seen anything like the models. Agree there is a deep westward current. However certainly the models have near surface currents.
    - What can we observe from altimetry? (Torge) Erik Mackie looked at this in his PhD for Cryosat-2: https://research-information.bris.ac.uk/en/studentTheses/southern-ocean-circulation-and-frontal-dynamics-from-cryosat-2-al
    - Steve: Doug Martinson (Lamont) studied countercurrents on southern side of Drake Passage and found that observations cannot discount countercurrents; Beadling et al., 2020 (DOI: 10.1175/JCLI-D-19-0970.1): more high-res models have more jets, also to the west of Drake Passage; countercurrents are typically deep currents, eddy or pressure driven, spurious or not, but not at surface like in discussed model examples
- Models also now resolve high latitude SO better, shelf is new focus region, slope current dynamics and Weddell gyre dynamics are getting more attention.
    - Steve: slope current is really important, also for Weddell Gyre and polynyas; new regime of science, where the gyre plays a role, instead of just ACC; the slope current is *the next big thing*;
    - Pat: strength of Weddell Gyre is linked to coastal slope current and links to counter current through Drake Passage, extremely sensitive to topography (particularly at 1/4)
    - Underrepresented freshwater fluxes close to Antarctica are hindering correct simulation of slope current
    - Interface of slope current with shelf: Morrison et al., 2020 “Warm Circumpolar Deep Water transport toward Antarctica driven by local dense water export in canyons” https://advances.sciencemag.org/content/6/18/eaav2516?intcmp=trendmd-adV
    - Role of the Antarctic Slope Front on the occurrence of the Weddell Sea polynya: Lockwood et al., 2021 “On the role of the Antarctic Slope Front on the occurrence of the Weddell Sea polynya under climate change https://journals.ametsoc.org/view/journals/clim/aop/JCLI-D-20-0069.1/JCLI-D-20-0069.1.xml

2) **Ice-ocean interaction:**

- ocean dynamics require ice shelf and iceberg processes to improve
  - Pierre Mathiot: using eORCA with open ice shelf cavities is only slightly more expensive than without cavities, since there are a few more ocean grid points but new algorithms are needed, all embedded in NEMO. The cost of 30.000 Lagrangian icebergs in 1/12˚ model is negligible; ice shelf cavities depend on resolution: in ORCA025 smaller ones like the Totten ice shelf is barely resolved, needs ORCA12 or even 1/24˚ for proper simulation; new parametersization in NEMO trunk
  - James Harle: at NOC sigma coordinates are tested for improved circulation in ice cavities at 1/12˚ (currently in a regional Weddell Sea setup)
  - icebergs do not interact with sea ice
  - Julie Deshayes: regarding SO dynamics : at LOCEAN we are "opening" the cavities in eORCA1 and eORCA025, with help from Pierre Mathiot and Nicolas Jourdain. This is a project led by Katherine Hutchinson (https://www.katofthesea.com/project-open). all results will be shared to the NEMO community, through ShaCoNEMO or other sharing platform
  - Bernard Barnier: Does this solve known issue with formation of the AABW? Are the right AABW properties simulated in the Argentinian Basin? Julie Deshayes: our motivation to "solve" this problem is precisely to include formation of HSSW within cavities... 1˚ grid seems to be sufficient to do that.
  - Pierre Mathiot: With ORCA you cannot open the cavities as the coastline does not extend beyond 78˚S, have to use eORCA. Charles Pelletier: With eORCA the coastline is better represented even when cavities are closed.
- how is Antarctic sea ice different from Arctic ice, adjust model tuning
  - Jan Klaus Riek: Should resolution of sea ice be even higher than that of the ocean? Guillaume Boutin: sea ice in SO is different as winds are different, rheology is not as well investigated as in Arctic Ocean
  - Large part of the SO is covered by a fragmented, divergent sea-ice cover. How do you transition from fragmented to unfragmented?
- land-fast sea ice
  - P.V. Huot: having land-fast ice is crucial for polynyas
  - grounded icebergs act as anchors/shields, modelling requires high-res topography; grounded icebergs important for polynyas as well
- Southern Ocean specific issues with AGRIF
  - Erik Behrens: nesting software lags behind recent NEMO developments and is not compatible with, for instance ice-shelf cavities and icebergs; therefore regional NEMO configurations are more often used to simulate the SO
  - icebergs cannot be exchanged between host and nest
  - grid resolutions of 1/12˚ and finer are needed to resolve ice-shelf cavity circulation properly, thus nesting with AGRIF is highly atractive; but due to technical issues with ice-related components using AGRIF in the SO is currently a challenge

3) **Biases:**

- How to deal with coastal freshwater? Salinity biases on and near the shelf cause major dynamical issues

- Which biases should be tackled first? Which matter most for global climate (change) and climate policy?
- How do we share our knowledge? How do we join forces to tackle biases efficiently?
    - Arne: Very important is an open exchange of working and non-working fixes. Nothing is more distracting and annoying to work on an aspect that is known to not work.
    - Discussion on platforms for exchange and archiving of solutions yielded no result

4) **Heat and carbon uptake:**
    - Advances regarding the role of the SO in nutrient supply and primary productivity at lower latitudes was discussed.
    - Role of climate forced wind changes in conjunction with eddy compensation briefly addressed.
    - Regarding biogeochemical model complexity vs. increased grid resolution: there is a case for using lower resolution in order to perform a number of ensemble runs.
    - Interesting topic: testing iron sources from iceberg melt
    - Pat: There is a major UK project called TICTOC on heat and carbon uptake in a lot of detail (https://projects.noc.ac.uk/tictoc/about). Other project called Sardine/RoSES (Ric Williams, https://roses.ac.uk/sardine/)

Model configurations with a Southern Ocean focus

Contact	Institution	Details
Ali Mashayak	Imperial College	1/24˚ SO
Erwin Lambert	Utrecht University	1/12˚ SO planned
James Harle	NOC/BAS	1/12˚ SO
Dorotea Lovino	CMCC	1/16˚ global
Erik Behrens	NIWA	1/16˚ Ross+Amundsen
Pierre-Vincent Huot	UCL	1/4˚ SO, 1/24˚ East Antarctica
Birte Gülk	Gothenburg Univ.	1/12˚ Weddell Sea, planned 1/60˚
L. Patara/T. Martin	GEOMAR	1/10˚ SO nest in 1/2˚ global ocean (+ biogeo-chem)
Robin Waldman	CNRM	global ORCA1 setup w/SO focus, running CMIP DECK experiments

eORCA users

Contact	Institution	details	cavities
Pierre Mathiot	UGA	regional Weddell	
Patrick Hyder	Met Office	global, coupled	open & closed
Erik Behrens	NIWA	global, SO nest	closed
Charles Pelletier	UCL	eORCA025	
Erwin Lambert	Utrecht University	eORCA12	
Julie Deshayes	LOCEAN	eORCA1 eORCA025	open (in progress)
G. Madec/ U. Hausmann	LOCEAN-IPSL	regional Weddell 1/12˚	
Robin Waldman	CNRM	eORCA1	