Report of the DRAKKAR meeting
Grenoble, 27-29 january 2014

Organizing committee
Bernard Barnier (CNRS, LGGE), Arne Biastoch (GEOMAR), Claus Böning (GEOMAR), Joël Hirschi (NOCS), Guillaume Maze (IFREMER, LPO), Adrian New (NOCS), Anne Marie Treguier (CNRS, LPO).

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

1. Scientific results with high-resolution global ocean simulations. Sub-sessions: Polar and Arctic processes, MOC variability, Agulhas and tropical latitudes, influence of model resolution.
2. The ocean: from forcing to coupling with the atmosphere
3. Status and future challenges of the DRAKKAR hierarchy of models. Sub sessions: Numerical schemes, discretizations, subgrid mixing processes, Stochastic parameterizations, Representation of surface waves
4. Joint session with Occiput/CHAOCEAN/MESO-Clip project: intrinsic/chaotic low-frequency ocean variability in OGCMs
5. Reanalyses/ DRAKKAR forcing sets.

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

The aim of the DRAKKAR consortium is to coordinate high resolution global simulations using the ORCA12 model based on NEMO. The annexes provides updated information on the sensitivity experiments carried out by the different groups, the reference ORCA12 experiments available for analysis, and the list of publications based on ORCA12.

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Scientific results with high-resolution global ocean simulations.

The objective was to present studies based on the DRAKKAR global models, either eddying (1/4° to 1/12°) or with high-resolution AGRIF nests. The morning block of this session covered a variety of oceanographic aspects in the subpolar/arctic Atlantic Ocean. A strong focus was put on the essential and important freshwater fluxes (liquid and solid) in this regions, which could potentially affect the deep water formation in the North Atlantic. In this context the effect of increasing horizontal resolution was discuss as well as the impact of mesoscale processes. Results were based on ORCA1, ORCA25, ORCA12 and regional 1/12° NEMO configurations.
In the subsequent session block results concerning the AMOC variability were discussed. Analogues to the recent observed decline were identified and possible reasons discussed.
The first block of the afternoon session dealt with future changes in the tropical and Agulhas regions. A key focus was put on the future changes of oxygen minimum zones in the Atlantic and Pacific in high resolution (1/10°) AGRIF simulations. Furthermore changes of the Agulhas Leakage to future wind changes were discussed as well as technics presented to estimate the Agulhas Leakage with altimetry.
The last block of the session focused on the importance of resolved mesoscale processes in dedicated studies with simulations with different horizontal resolution. Results of the first “Nest-in Nest”AGRIF configuration in the subpolar North Atlantic were presented, allowing dedicated regional high resolution studies in a global context.

Highlights

Regarding the polar and subpolar oceans, three presentations explored numerical simulations at 1/12° and showed improvements or new dynamics compared with lower resolution models (Y Aksenov, P Myers, F. Roy, M. Chevallier). A recirculation around the Belgica Bank near Fram strait has been analyzed in ORCA12. This recirculation has strong impacts on the connection between the Arctic and the Nordic seas and its variability appears related to the wind stress (Y. Aksenov).

ORCA12 and ORCA025 simulations show AMOC minima such as the one observed in 2010 by the RAPID array. The long time series from the models have been used to investigate the relationship of these minima to the atmospheric forcings (A. Blaker). The long ORCA12 simulation was also used to study the currents around the Canary Island with an emphasis on the links between the wind stress curl and density variations.

Improvements brought about by high spatial resolution have been documented: improvement of oxygen distribution due to a better representation fo equatorial currents in the Atlantic (O. Duteil), improvement in the représentation of the Agulhas leakage (J. Durgadoo), boundary currents of the subpolar gyres (C. Talandier, E. Behrens). However, biases in water mass properties (as shown by global zonal means of temperature and salinity) are found to be quite similar in ORCA12 and ORCA025 (P. Hyder).

Discussion items

About sea ice models:

- the MetOffice is using the CICE model (developed at Los Alamos National Lab).
- For LIM2 users, there is a need to move to LIM3 (multi-category ice): better representation of ice-albedo feedbacks, ice growth, etc. However LIM3 has not yet been tested in global high resolution configurations (ORCA025, ORCA12). Mercator will test LIM3 by the end of 2014. The cost (CPU time) may be an issue.
- salinity restoring under sea ice is done differently in different groups (no SSS relaxation under sea ice in the Kiel group, relaxation in the other groups).

About enclosed seas and runoffs:
Need to represent the black sea and semi enclosed seas, with the purpose of coupling to the atmosphere.
The Mercator-Canada collaboration is developing improved runoffs in the polar regions.

The ocean: from forcing to coupling with the atmosphere

This session included talks and discussions about the limitations of forced ocean models, the challenges of coupling with the atmosphere, and other possible strategies to represent the variability of the past decades (e.g., partial coupling, coupling the ocean to an atmospheric boundary layer model, restoring the atmospheric model).

Highlights
Sébastien Masson presented preliminary results of the PULSATION and EMBRACE projects. The tropical oceans are coupled with an atmospheric model (WRF) with capability of zooms up to 1/12° in the ocean, atmosphere or both. The idea is to explore the impact of ocean-atmopshere coupling at small scales (e.g., for tropical cyclones) and also the large scale/global impact of such coupled mechanisms.
The project involves significant technical developments: introduction of the OASIS coupler in WRF, nesting capability in NEMO coupling interface, using XIOS with the coupler and AGRIF... Setting up new coupled configurations requires a large number of tests to choose the right parameters (130 tests at 3/4° resolution!).
Preliminary results with high resolution nests in upwelling regions suggest that the upscaling effects are larger in the atmosphere than in the ocean.

Bruno Deremble (FSU) presented a new strategy to force ocean models: Cheap AML, a simple atmospheric boundary layer model to replace ~~bulk formulaes~~ the bulk formulas with a fixed atmosphere. One expects a better representation air-sea exchanges. The model is still very crude (prescription of a constant boundary layer height H, for example) and will need to be refined. The implementation in NEMO and a series of tests with ORCA2 was done By Bruno in June 2012 during his visit to Grenoble and will be continued in Kiel (R. Abel).

Discussion items

There are two big problems with the way we forced the ocean in Drakkar or in CORE (with a fixed atmospheric state and bulk formulae for air-sea fluxes):
- the air temperature does not respond to SST perturbations
- there is no feedback between evaporation (recalculated with model SST) and precipitations (prescribed).

- The increase of spatial resolution in the ocean is beneficial to the coupled systems (U.K. MetO results with ORCA025, Scaife et al). The weather prediction in the U.K. will use ORCA12.
- coupled models can have large biases. Example (MetO): the Southern Ocean warm bias (which seems to come from the atmosphere: too much incoming shortwave radiation),
- The move toward more ocean-atmosphere coupling is necessary when we consider long time scales (decadal) because of the missing feedbacks in forced mode.
- need for realistic winds to force an ocean model. Perhaps force with observed winds but couple the atmospheric temperature and humidity?
- is it possible to have forced high resolution atmosphere and ocean run separately, but in interaction with a coupling at low spatial resolution? (L. Terray)

Status and future challenges of the DRAKKAR hierarchy of models

Highlights

Caveats in using NEMO's EEN momentum advection scheme: Nicolas Ducousso (LGGE, Grenoble) identified two problems with the "vector form - energy and enstrophy conserving momentum advection scheme" that is the most widely used scheme in NEMO at eddy resolving resolution. The first problem is related to the formulation of the lateral boundary condition for potential vorticity at the coast. The standard formulation leads to a spurious behavior in the canonical case of a vortex impinging on a wall with a free-slip condition ("mirror" effect). A correction is proposed (it is included in NEMO 3.6). The second problem is a computational instability originally pointed out by Hollingsworth et al (QJRMS 1983). The instability arises when the EEN scheme is used in a three-dimensional (multi-layer) context. The solution proposed by Arakawa (2000) has been implemented in NEMO. Both corrections have been tested in ORCA025 (in twin sensitivity experiments) and impacts are being assessed. More tests with ORCA12 are planned in 2014.

Wave forcing: Olvind Breivik presented results showing the impact of wave forcing in ocean only and coupled ocean-atmosphere simulations. NEMO is forced with fluxes of momentum and TKE obtained from the WAM wave model. The modified TKE has the largest effect and modifies the sea surface temperatures (SSTs). This is particularly pronounced in the summer hemisphere and along the eastward extensions of western boundary currents (Gulf Stream, Kuroshio). Early results also suggest that the wave forcing reduce the SST bias that typically affect coupled models.

Stochastic parameterisations: Promising results regarding stochastic parameterisations were presented by Jean Michel Brankart. The largest uncertainties that need to be corrected by the stochastic parameterisations reside in the horizontal density gradients.

Discussion about NEMO
Julien Le Sommer presented the prospective that has been carried out in 2013. A "white paper" describing the roadmap for developments in the next 4/10 years is almost ready. The first priority for NEMO in 2014-2015 is "simplification", which means that some pieces of code currently used in Drakkar (e.g., dimg output) may become obsolete soon.

Close collaboration between the NEMO system team and Drakkar developers is required.

Joint session with Occiput/CHAOCEAN/MESO-Clip project

This session presented recent advances in scientific understanding of intrinsic/chaotic variability in the global ocean as well as new analysis techniques. The aim was also to present ongoing projects on this subject and discuss possible synergies.

Highlights
Intrinsic/chaotic variability in SST and SSH: Guillaume Sérazin showed results from his analysis of the variability in SSH and SST in interannually (50 years) and climatologically (85 years) forced ORCA12 simulations. Particular emphasis was on the spatio-temporal structure of the SSH and SST variability and on assessing to what extent this variability is intrinsic/chaotic.
Intrinsic/chaotic variabity in meridional overturning: Sandy Gregorio and Thierry Huck looked at the intrinstic/chaotic variability in the meridional overturning circulation using either realistic (ORCA025, Sandy Gregorio) and idealized (Thierry Huck) model configuration where ocean mesoscale eddies are present.
Fingerprints of AMOC variability: Claus Böning showed that in a suite of ORCA experiments (1°, ¼°, 1/12°) the surface western boundary current at around 6°N along South America was a good indicator for the decadal AMOC variability.

Discussion items
Thierry Penduff and Joël Hirschi gave an overview about their respective projects (OCCIPUT, MESO-CLIP). Items that led to more discussions are:
- Ensemble construction in OCCIPUT: what is a good strategy for the planned 50 member ORCA025 ensemble? What initial conditions should be used and how should these be perturbed? Also what should the spinup strategy be? This discussion was then taken up again the next day during the OCCIPUT meeting.
- How to measure divergence of model trajectories due to mesoscale activity? In the preliminary work undertaken in MESO-CLIP quite simple metrics were used (e.g. cross-decorrelation) but it was suggested to consider other approaches as well.

Reanalyses/ DRAKKAR forcing sets

The aim of this session was to discuss global ocean reanalysis products and to coordinate the preparation of forcing sets based on ECMWF atmospheric data.

Highlights
Results from two global reanalyses using ORCA025 have been presented (Maria Valdivieso and Keith Haines for the University of Reading and Laurent Parent for the Glorys2v3 reanalysis at Mercator). A comparison of 15 or 16 global ocean reanalyses worldwide will be published in the next issue of CLIVAR exchanges.

Simon Josey showed the influence of Tropical Pacific Buoy Observations on ERA reanalysis and its consequences on the air-sea heatf in DFS4 and DFS5. A pattern of alternating net heat flux anomalies of ± 20 Wm-2 in the annual mean for the DFS4 product, co-located with the Tropical Pacific buoys, is observed in the early-mid 1990s. The causes and implications of this pattern have been discussed with reference to near surface humidity biases in the ERA Reanalyses. The problem with assimilation of TAO moorings affects wind divergence and makes ECMWF humidity fields unreliable in the tropical Pacific. This impacts the DFS forcing sets. NCEP forcing does not have this problem.

Discussion items

A new DFS5.2 forcing set based on ERA40 and ERA Interim is almost ready (Bernard Barnier). Many difficulties have been found, for example regarding discontinuities between ERA40 and ERAI.

How do we best develop forcing fields for model runs? Would it be worth employing OAFlux type methodology (combination of multiple reanalysis and satellite field) instead of single reanalysis (ECMWF) in the next generation of DFS fields?

Summary of discussions regarding global 1/12° simulations

Three groups (Mercator, NOCS, LGGE) have tested the UBS scheme (higher order advection scheme similar to the one used in the ROMS model). We agree that the scheme is not appropriate for tracers because it creates too much diffusion across isopycnals (the problem identified in ROMS by P. Marchesiello). A rotation of the diffusive part of the scheme is required (the implementation is in progress, Gurvan Madec et al).

All the groups will use time-splitting rather than implicit free surface, as the gain in CPU time is very significant (almost 30% for ORCA12). The implicit free surface will soon be obsolete in NEMO.

There is a consensus to use the new equation of state (TEOS10) as soon as possible when it is available in NEMO (end of 2014?).

Publication strategy

The first papers using ORCA12 simulations have been published or submitted in 2013 (see annex 3).

Regarding the "ORCA12 reference paper", the common paper between operational applications and sensitivity studies has not been completed yet (the operational simulations had too many differences between them, making the interpretation difficult). Another possibility is to write a common paper documenting globally the impact of going from 1/4° to 1/12° resolution. Bernard will get in touch with the groups so that everyone can contribute by pointing out one physical process. The processes should be easy to document by simple, standard diagnostics.

Anne Marie proposed also to write a short paper that would advertize the DRAKKAR coordination (a note in EOS? an update of the 2007 "clivar exchanges" paper?). The aim of the paper would be to synthesize the applications of ORCA12 that have already been published and provide a prospective outlook.

Plans for new ORCA12 simulations in 2014

LGGE

In 2014 the Grenoble team will run a long (30 years?) ORCA12 simulation with NEMO 3.5/3.6 and 75 levels, using the latest version of DFS5 forcing. The increase of the number of vertical levels from 46 to 75 is motivated by improvements in the Arctic and in upwelling areas. In this way, the same vertical resolution will be used NOCS, Mercator and Grenoble. The use of GLS instead of TKE for the vertical mixing, as proposed by Mercator, will be considered (it will be tested first at lower resolution).

NOCS

A new ORCA12 simulation has been run at NOCS with the new bathymetry (v3.3) and a new forcing (DFS5.1). The Gulf Stream separation is worse than in the previous simulation (i.e. overshooting as seen for ORCA025). The next step was to ensure that the good Gulf Stream separation seen in the original NOC simulations (NEMO v3.2/v3.3.1) can be reproduced in the new code (NEMO 3.5). Reassuringly this is the case: using the old bathymetry (v1), TVD advection and DFS4.1 forcing we can reproduce the realistic separation seen in the old simulation. We haven't identified the main cause for the good/bad separation in ORCA12. 10-year tests currently underway (where we systematically assess the impact of the bathymetry, surface forcing and lateral boundary conditions). The TVD scheme is used since a problem has been identified with the UBS scheme (see above). The main simulation performed in 2014 will be a new control simulation (1958)1978-2012 where from 1990 onwards we will include biogeochemistry (MEDUSA).

GEOMAR

The Kiel group will not run long simulations in 2014 (computer time available amounts to about 15 years of run), but there are plans to do more in 2015. For this year the 46-levels configuration will be kept for a few sensitivity tests.

MERCATOR

In 2014 Mercator-Ocean will perform a new ORCA12 simulation (34 years?). The first part of this simulation will be performed during the VSR of the new Météo-France computer. The characteristics are the same than the previous ORCA12 simulation, presented at this DRAKKAR meeting, except:
i) Bathymetry v3.5 instead v3.4 (v3.5= v3.3 + drag at a minimum depth of 7m (=v3.4); correction of 7 points on the overlapping band along India (pb in mask computation); Channel in Red Sea modified (at 200 meters depth instead of 120m).
ii) TVD scheme with an explicit laplacian isopycnal diffusion (100m2/s) will be used for the advection of the tracers (computation of the isopycnal slopes increases the elapsed time of 15% !).

iii) The momentum advection will be computed in vector form with the EEN scheme, which included the modifications presented by Nicolas Ducousso at the meeting. An explicit bilaplacian diffusion is added (-1.e10m4/s) and a laplacian one Southward of 65°S (100m2/s) due to numerical instabilities with the EEN scheme

MetOffice
At the MetOffice we are getting NEMO-CICE with ORCA 1/12th working with lakes.
ORCA12 will be firstly used for coupled NWP (weather forecasting) and the technical build is supposed to be completed by June 2014. Furthermore, Helene Banks is coordinating further work with the coupled orca12, e.g., longer timescale runs for climate issues.
In 2014 we hope to do at least:
- forced simulations with optimized NOC set up for ~10 years (not sure which forcing set yet, but possibly consistent with Andrew's final optimized run to allow direct NEMO-LIM NEMO-CICE comparisons).
- coupled simulations with high resolution atmosphere N768 for ~10 years.

Annex 1: Available ORCA12 sensitivity experiments

Sensitivity experiments using ORCA12 that may be of use to other Drakkar partners

Group experiment year of the run	Duration	Vertical grid	Forcing	Other parameters
Kiel ORCA12-K001 2011	1978-2007	46 levels	CORE v2 relative wind	ice Lim2 VP. No SSS restoring under sea ice. partial slip (shlat=0.5)
Kiel ORCA12-K003 2012	1978-2007	46 levels bathy v3.3	CORE v2 rain reduction	ice Lim2 VP. Very weak SSS restoring. No SSS restoring under sea ice. free slip. Reduced biharmonic
Grenoble ORCA12.L46-MAL95 2011	1989-2007 restart fm K001	46 levels	ERA-I relative wind	ice Lim2 VP. partial slip (shlat=0.5)
Grenoble ORCA12.L46-MAL85 - 2011	1978-1992	46 levels	DFS4.1 relative wind	Flux form momentum advection, free slip (shlat=0)
Grenoble ORCA12.L46-MAL105b 2012	1989-2011	46 levels bathy v3.3	ERA-I absolute wind	SSS restoring 30days/50mEEN momentum . advection, free slip (shlat=0) par no-slip in special places.
Mercator ORCA12.L50-T321 - 2012	1999-2010	50 levels	ERA-I absolute wind	free slip (shlat=0)
Mercator ORCA12.L75-TRBB359 - 2013	1979-2012	75 levels	ERA-I absolute wind	NEMOv3.5, Time-splitting_mo, GLS_mo, UBS on dynamic and tracers, lim2_evp
NOCS ORCA12.L75-N0083 - 2012	1978-2010	75 levels	DFS4.1	VVL option

Annex 2: available ORCA12 reference experiments

List of long, well documented experiments run for the purpose of scientific analysis and comparison with data.

Experiment year of run Drakkar team Computing centre	Duration documentation	Characteristics	Strengths	Weaknesses
ORCA12.L46-GJM02 2013 Grenoble IDRIS (France)	85 years	46 levels. bathy v3.3 Forcing: Climatological DFS4.4 absolute wind +3D relaxation Weddell sea LIM2 Ice EVP first, then VP from year 12 on.	Long climatological run, stable since year 16. *Separation and strength of GS.* Confluence and ZA. *Transport at Bering, Cable, ACC &ITF.* AMOC strength. *Overflows strength and steadiness in NA.*	Polynia in Weddell sea in the first years, fixed with LIM2 VP + restoring in Weddell Sea. *Salt bias in LabSea.* Alboran Gyres. *No convection in MedSea.* Unrealistic SSH & SSS trends. *Warm bias in Nino1+2.* Winter MLD too deep in Lab Sea. *"Weak" EKE.*
ORCA12.L46-MJM88 2013 Grenoble CINES (France)	55 years (1958-2012)	46 levels. bathy v3.3 Forcing: interanual DFS4.4 absolute wind +3D relaxation Weddell sea LIM2 VP	First long interanual run with ORCA12. *Companion simulation of GJM02.* Separation and strength of GS. *Confluence and ZA.* AMOC strength. *Transport at Bering, Cable, ACC &ITF.* Winter MLD in LabSea. *Overflows strength and steadiness in NA.* Arctic Sea Ice extent.	Same Weddel sea restoring for coherency with GJM02. *Antarctic Sea Ice extent.* Salt bias in LabSea. *No convection in MedSea.* Alboran Gyres. *Unrealistic SSH & SSS trends.* Warm bias in Nino1+2.

ORCAR12-N001 2013 Southampton, NOC	33 years (1978-2010)	75 Levels bathy v1 Forcing: DFS4.1 Relative wind LIM2 Ice VP Non-linear free surface	Realistic separations and strength of Gulf Stream and Kuroshio Good representation of the Subpolar Gyre region Realistic overflow strength in the NA	Weak ACC (still decreasing at the end of the run) Variability of WBCs too weak NA Overflow properties (T , S) not maintained

Annex 3: ORCA12 publications

Published or in press:

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

Duchez, A., Frajka‐Williams, E., Castro, N., Hirschi, J., & Coward, A. (2014). Seasonal to interannual variability in density around the Canary Islands and their influence on the Atlantic meridional overturning circulation at 26° N. *Journal of Geophysical Research: Oceans*, in press, DOI 10.1002/2013JC009416

Treguier, A.M., J. Deshayes, J. Le Sommer, C. Lique, G. Madec, T. Penduff, J.-M. Molines, B. Barnier, R. Bourdalle-Badie, and C. Talandier, 2013: Meridional transport of salt in the global ocean from an eddy-resolving model. Ocean Science, in press, 10, 2293-2326, 2013. www.ocean-sci-discuss.net/10/2293/2013/doi:10.5194/osd-10-2293-2013

Submitted:

Barrier, N., J Deshayes, A.M. Treguier and C. Cassou, 2014: Interannual to decadal heat budget in the subpolar North Atlantic. Submitted to Progress in Oceanography.

Blaker, Adam T., Joël J-M. Hirschi, Gerard McCarthy, Bablu Sinha, Sarah Taws, Robert Marsh, Andrew Coward, Beverly de Cuevas: Historical analogues of the recent extreme minima observed in the Atlantic meridional overturning circulation at 26N, *Climate Dynamics*, submitted

Alice Marzocchi, Joël J.-M. Hirschi, N. Penny Holliday, Stuart A., Cunningham, Adam T. Blaker, Andrew C. Coward: The North Atlantic subpolar circulation in an eddy-resolving global ocean model, Journal of Marine Systems, submitted.

Annex 4: List of participants (80)

France
LGGE - Grenoble (12): Bernard Barnier, Jean Marc Molines, Thierry Penduff, Nicolas Ducousso, Hubert Gallée, Julien Le Sommer, Jean Michel Brankart, Guillaume Sérazin, Sandy Grégorio, Quam Akutevi, Pierre Brasseur, Aurélie Albert
LJK - Grenoble (2): Laurent Debreu, Florian Lemarié
LPO/IFREMER - Brest (5): Claude Talandier, Anne Marie Treguier, Guillaume Maze, Matthew Thomas, Thierry Huck
LOCEAN/IPSL - Paris (8): Gurvan Madec, Marie Alice Foujols, Julien Jouanno, Christophe Herbaut, Sébastien Masson, Claire Levy, Anne Cécile Blaizot, Martin Vancoppenolle
LSCE - Orsay (5) : James Orr, Olivier Marti, Jérôme Servonnat, Timothée Bourgeois, Christian Ethé
CERFACS Toulouse (4): Sophie Valcke, Laurent Terray, Marie-Pierre Moine, Laurent Bessières
MERCATOR-Ocean - Toulouse (4): Laurent Parent, Gilles Garric, Romain Bourdallé-Badie, Matthieu Chevallier

U.K.
NOC - Southampton (10): Adrian New, Joel Hirschi, Yevgeny Aksenov, Aurélie Duchez, Andrew Coward, Adam Blaker, Alex Megann, Lucia Hosekova, George Nurser, Simon Josey
ESSC - Reading (2): Keith Haines, Maria Valdivieso
University of Reading (3): Remy Tailleux, Till Kuhlbrodt, David Ferreira
BAS Cambridge (1): Pierre Mathiot
University of Oxford (U.K)(1): Camille Lique
UKMetO (U.K.) (2): Pat Hyder, Chris Harris
ECMWF (3): Øyvind Breivik, Hao Zuo, Sarah Keeley

Germany
GEOMAR - Kiel (9): Wonsun Park, Raphael Abel, Markus Scheinert, Taewook Park, Jonathan Durgadoo, Eric Behrens, Klaus Getzlaff, Claus Böning, Olaf Duteil

Other countries
University of Stockholm (2): Fabien Roquet, Laurent Brodeau
University of Alberta, Canada (1): Paul Meyers
Environnement Canada (1): François Roy
U. McGill (1): Casimir de Lavergne
CICESE - Ensenada (Mexico) (1): Julio Sheinbaum
UC Louvain La Neuve (Belgium) (1): Johanthan Raulier
Utrecht Univ. (Netherlands) (1): Dewi Le Bars (now at LOCEAN)
FSU (USA) (1): Bruno Deremble