INTERNATIONAL COUNCIL FOR SCIENCE

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

WORLD METEOROLOGICAL ORGANIZATION

WORLD CLIMATE RESEARCH PROGRAMME

Report of the 7th Meeting of the CLIVAR Working Group on Ocean Model Development

24-26 August 2007
Bergen, Norway

March

ICPO Publication Series No.130

WCRP Informal Report No. 6/2008

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organisation, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO. The scientific planning and development of CLIVAR is under the guidance of the JSC Scientific Steering Group for CLIVAR assisted by the CLIVAR International Project Office. The Joint Scientific Committee (JSC) is the main body of WMO-ICSU-IOC formulating overall WCRP scientific concepts.

Bibliographic Citation

INTERNATIONAL CLIVAR PROJECT OFFICE, 2008: Report of the 7th Meeting of the CLIVAR Working Group on Ocean Model Development. March. International CLIVAR Project Office, CLIVAR Publication Series No. 130. (not peer reviewed).

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Action Items and Recommendations

1. CORE-related references should be placed on the WGOMD CORE webpage, including annotations (give references and comments to A. Pirani).
2. WGOMD needs to emphasize the limitations of CORE, such as the caution needed when interpreting the interior ocean. Metrics should be proposed to quantify errors due to drift.
3. WGOMD has agreed to continue working with the Large & Yeager CORE forcing, maintaining a close relationship with, and providing feedback to W. Large and colleagues at NCAR (All).
4. Inform WGOMD when updated Large & Yeager dataset is available (A. Pirani).
5. WGOMD should be making recommendations on data that should be saved, data format etc for the climate modelling community, by advising WGCM. For example, in eddy-permitting/resolving simulations, should correlations be saved?
6. CORE-II participants should provide details on the boundary conditions being applied, initialisation and the complexity of the ice model being used so that these details can be included on the WGOMD CORE webpage together with a table of participants, planned experiments and status (CORE-II participants to A. Pirani).
7. Provide details of Arctic reconstruction project (R. Gerdes and H. Drange)
8. Recommend that NCAR intialisation code should use a more realistic sea-ice distribution, and should correct for unrealistic ice volume off the coast of Siberia.
9. Provide a paragraph on the alternatives to salinity restoring (H. Drange).
10. Each CLIVAR basin panel should be requested to produce a list of questions and metrics to be tested in a CORE-II type experiment, including a view on the timescales of the processes that could be addressed by a 50-year experiment timeframe. Each panel should also be asked to name a panel member for liaison.
11. Preliminary CORE-II results will be shown at the next Pacific Implementation Panel meeting on 29-30 November 2007, Guangzhou, China (C. Böning)
12. Prepare references and information relevant to the CORE-III experiment for the WGOMD webpage (R. Gerdes).
13. Identify what data sets are being used by the Met Office Hadley Centre to assess the ocean and sea-ice components of HadGEM3 and how the metrics proposed by the Met Office Hadley Centre compare with the metrics GSOP is considering (H. Banks)
14. WGOMD needs to input to WGCM an ocean-ice model view of how climate models are assessed (WGOMD)
15. Provide input to GSOP (D. Stammer) on the above issues for the synthesis evaluation document that is in preparation (S. Griffies)
16. Circulate GSOP draft synthesis evaluation document to WGOMD (A. Pirani)
17. Summarize observational data quality control activities at the Met Office Hadley Centre (H. Banks)
18. What are the official GODAE metrics? Have class I-IV metrics with all the data on the same grid for all the models for the Atlantic. This needs to be extended globally (E. Chassignet)
19. Feedback and input on ideas for developing a webpage for evaluating ocean models, making recommendations for data saving and a classification of metrics (All to A. Pirani and S. Griffies)
20. WGOMD needs to recommend what ocean data needs to be saved in the next IPCC assessment process (all), and work towards formulating what should constitute the basis for the assessment of climate models (S. Griffies, H. Banks) and regional models (E. Chassignet).
21. WGOMD strongly recommends to PCMDI that native ocean grids be supported.
22. Tools for converting between grids (eg those available at NCAR) should be shared.
23. WGOMD recommends that participants to a future AR5 submit a 500 year CORE-I simulation as well as CORE-II, depending on progress.
24. Start planning content and invited talks, logistics and sources of funding for the proposed workshop (H. Banks, S. Griffies, A. Pirani).

1. Introduction

The 7th Session of the CLIVAR Working Group on Ocean Model Development (WGOMD) was held on the 25-26 August 2007, generously hosted by H. Drange of the Nansen Centre (NERSC) and the Bjerkness Centre (BCCR) in Bergen Norway. A list of participants is at Appendix A and the meeting agenda is at Appendix B. This meeting focused on the major issues that the panel needs to make progress on, namely the CORE experiments and ocean model evaluation metrics. The following reports on regional and institutional activities from individual WGOMD members are available on the meeting webpage (http://www.clivar.org/organization/wgomd/wgomd7/wgomd_bergen.php):

- Summary of GFDL ocean climate modelling activities: 2005-2007 (S. Griffies)
- Modelling activities in Canada (R. Greatbatch)
- UK activities in ocean model development (H. Banks)
- Summary of NCAR ocean modelling activities (G. Danabasoglu)
- Update on global and large scale ocean modelling based on the NEMO system (A. M. Treguier and G. Madec)
- Ocean model development in Germany (C. Böning)
- Ocean modelling activities in the East Asia Region (H. Tsujino)
- Ocean general circulation development in the Scandinavian Countries (H. Drange)

The WGOMD meeting was preceded by the Layered Ocean Model Workshop (see the following webpage for details: http://oceanmodelling.rsmas.miami.edu/lom/index.html) and the CLIVAR WGOMD Workshop on Numerical Methods in Ocean Models (http://www.clivar.org/organization/wgomd/nmw/nmw_main.php). The Workshop on Numerical Methods in Ocean Models is summarized in Section 7 of this report, with an extended workshop report available (CLIVAR Publication Series no. is 128/WCRP No. 4).

The WGOMD meeting coincided with the Inaugural Meeting: Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES) (http://clic.npolar.no/theme/sophocles.php). WGOMD joined part of a session of the SOPHOCLES meeting and contributed some presentations outlining the CORE experiments. The SOPHOCLES community is interested in the CORE-II framework, particularly run at high resolution, though processes of interest such as water mass formation, are sensitive to details of the experimental protocol, in particular salinity restoring and coastal run-off. The question was raised of how restoring is applied under sea ice. More details, including the key processes being examined, are given on the SOPHOCLES project in Appendix E.

2. Overview of WCRP strategic framework and its implementation

The World Climate Research Programme (WCRP, http://wcrp.wmo.int/) published in August 2005 its Strategic Framework: 2005-2015: Coordinated Observation and Prediction of the Earth System. The document reiterates the WCRP objectives to determine the predictability of climate and the effect of human activities on climate. The strategic framework seeks to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. The key issues are:

- Move from physics-only to Earth-System models (with IGBP, http://www.igbp.net/)
- Prediction across all timescales: "seamless predictions"
- Develop sustained climate observing system with GCOS, GEOSS etc…
- Integration of models and data: 1) use of data assimilation to initialize models over widest range of climate prediction timescales possible; 2) synthesis through reanalysis (atmosphere, ocean, coupled)
- Link to applications through existing mechanisms (e.g. START http://www.igbp.net/, World Climate Application Programme) and new ones

The 28th session of the WCRP Joint Scientific Committee was held in Zanzibar, Tanzania, from 26 to 30 March 2007. The meeting aimed to determine the future of the WCRP and review progress in implementing its Strategic Framework 2005-2015. All the documents prepared for the JSC-28 are available on the WCRP website: http://wcrp.wmo.int/TableDocs.html.

2.1. WCRP cross-cutting activities
Particularly relevant to CLIVAR is the outcome of the JSC Task Team on Implementing the WCRP Strategic Framework which recommends WCRP to focus on cross-cutting issues aimed at meeting society's and stakeholder needs. The cross-cutting activities identified by JSC are:

- Anthropogenic Climate Change
- Atmospheric Chemistry and Composition
- Monsoon and the Year of Tropical Convection
- Decadal Prediction
- Extreme Climate Events
- International Polar Year
- Sea-level Rise
- Seasonal Prediction

2.2. Funding issues
The total budget allocated to core CLIVAR activities will be reduced considerably for the period 2008-9 as a result of introducing cross-cutting activities within WCRP, zero nominal growth in WCRP budgets and the ever weakening state of the US dollar. It may be that funding being allocated to the WCRP cross-cutting activities will be relevant for the CLIVAR Panels and Working Groups directly involved, as is the case for WGSIP in terms of the decadal prediction activity.

How best to handle the lack of resources is still not clear. It is hoped that the CLIVAR Panels and Working Groups will continue to aim to meet every 18 months, generally in conjunction with a scientific workshop or conference. Since CLIVAR funding will be insufficient to fully support all groups, meetings may need to actively seek additional sources of funding. WGOMD noted the situation.

3. Review of WGOMD activities – Past, Present and Future

The terms of reference of WGOMD have been updated through the removal of the qualifier on the first term of reference that previously limited WGOMD activities in stimulating the development of ocean models for research in climate and related fields to decadal and longer timescales at global scales. This focus on longer, global timescales originated from WGOMD's original role as support for WGCM. WGOMD has extended this term of reference to shorter and smaller spatial scales since its focus has been extended to regional and coastal problems, as well as being involved in ENSO-related issues.

3.1. Assumptions made by WGOMD

- Ocean models are relevant to understanding climate and predicting potential future changes.
- The space-time scales relevant for WGOMD considerations extend from the global climate scale to the regional and increasingly the coastal scales.
- Scientifically based model fundamentals produce robust model tools for use in climate science. *This is the science of ocean models*:
  - Dynamical assumptions
  - Numerical methods
  - Physical parameterisations
  - Rational, complete, and pedagogical model documentation
- Well-defined and fully documented experimental designs for model simulations are essential to realize robust results that can be reproduced by other groups. By absenting the full documentation of model designs, one is doing irreproducible model integration (not science). *This is the science of ocean modelling*:
  - Forcing datasets
  - Bulk formulae
  - Restoring terms
  - Coupling methods
  - Integration times
  - Analysis methods

3.2. WGOMD Mission

A central mission of WGOMD is to facilitate the maturation of ocean models, and the use of ocean models in well defined and reproducible ocean modelling simulations.

WGOMD aims to realize this mission by providing pedagogical peer-review survey papers that document models and the experimental design of simulations.

It also does so by organizing topical workshops that bring elements of the oceanography community together to discuss research and development areas relevant to increasing the scientific integrity of models and their simulations.
Realizing this mission (or some aspect of it) allows WGOMD to provide scientifically based advice to other CLIVAR panels and to WGCM.

This mission remains ongoing, with some success. However, further efforts are required to make routine use of ocean models by a scientifically literate researcher a process that produces useful scientific results.

3.3. Key Contributions to the Modelling Community

- Review paper: Pedagogically documents state-of-art in ocean climate models and had a leading role affecting AR4 ocean model development (Griffies *et al*., 2000):
  - Pedagogical survey of ocean climate model methods and parameterizations
  - Highlighted vertical coordinates as key for model algorithms, with many complementary attributes between coordinates.
  - Influenced AR4 ocean climate model developments.
  - A basis for ongoing research efforts at improving model fundamentals.
- Workshops: Topical workshops that facilitate collaboration, communication, and education:
  - Princeton/GFDL 2004: State-of-art in Ocean Climate Modelling
    - Key developers of AR4 ocean climate models discussed their methods, parameterisations, and results.
    - Experts in ocean physics and numerics scrutinized the AR4 models and made recommendations for next round of IPCC ocean models.
    - Community input to the WGOMD's efforts at establishing an OMIP. A key outcome was to propose CORE as a science-based collaborative project, rather than push forward with a mandatory OMIP, as such was considered premature.
  - Hobart/CSIRO 2005: Southern Ocean Modelling
    - Southern Ocean is key to represent with high fidelity in climate models, as it represents a huge sink for heat and carbon, and the processes active have importance to all ocean basins.
    - Science workshop discussed and debated methods of simulating and analyzing Southern Ocean physical and biogeochemical processes.
    - Ten lectures with discussions provided pedagogical surveys of key aspects of the Southern Ocean.
  - Bergen 2007: Numerical Methods for Ocean Models
    - Discuss and debate novel methods for developing the next generation of ocean models for global, regional and coastal applications.
    - Bring together key practitioners and algorithm developers for eight provocative and pedagogical sessions.
    - Enhance communication amongst a community of algorithm developers who typically do not have the opportunity to gather in such focused workshop settings.
- Coordinated Ocean-ice Reference Experiment (CORE):
  Benchmark experiments for global ocean-ice models and a step towards developing an Ocean Model Intercomparison Project (OMIP). The CORE-I proof of concept project includes seven international modelling groups and consists of three ocean model coordinate classes (geopotential, isopycnal and hybrid). A peer-review paper is currently in preparation illustrating CORE-I results with the seven ocean-ice models each run for 500 years (Griffies *et al*., 2008).

4. Review of the Coupled Ocean-ice Reference Experiment (CORE)

4.1 Overview of CORE

The key assumptions that have led to the concept of CORE are that:

- Global ocean-ice modelling is a useful exercise.
  - Provides mechanistic understandings of the ocean climate system.
  - Provides a key step towards coupled climate models.
- Comparing simulations of different global ocean-ice models is a useful exercise:
  - Renders more robust understanding.
  - Improves the models, especially by identifying outliers.
  - Refines the experimental design, including forcing.
- The development of a protocol for running ocean-ice models is of interest to the modelling community to help facilitate simulation comparisons.

The key goals of CORE are to:

- Provide a workable and agreeable experimental design for global ocean-ice models to be run for long-term climate studies.
- Establish a framework where the experimental design is flexible and subject to refinement as the community gains experience and provides feedback.

CORE does not constitute an Ocean Model Intercomparison Project (OMIP) as WGOMD is not prepared to formally sanction the current CORE protocol of forcing dataset until the community has had time to provide feedback. This means that CORE is a research project that is voluntarily conducted by interested scientists and there is no formal oversight committee or data repository arrangement in place. This does not prevent the project from eventually evolving into an OMIP.

As R. Gerdes pointed out, ocean-ice model experiments are useful since they are less costly than fully coupled experiments, they can be used in hindcast mode to reproduce the history of ocean and ice variables and hence help in the interpretation of observations, they allow for the understanding of processes in the absence of biases introduced by the atmospheric model and hence potentially give superior representations (compared to the ocean component of a coupled model) of key physical, chemical and biological processes and so help in model development.

Three CORE experiments have been endorsed by WGOMD:

<u>CORE-I</u>

To investigate the climatological ocean and sea-ice states realised through multi-centennial simulations forced by idealised repeating normal year forcing that has been derived from 43 years of interannually varying forcing, retaining synoptic variability with a seamless transition from 31 December to 1 January (Large and Yeager, 2004).

<u>CORE-II</u>

To investigate the forced response of the ocean in hindcast mode. The experiment will be forced by the interannually varying dataset from 1958-2004 (soon to be updated to 2006) of Large and Yeager (2004).

<u>CORE-III</u>

To investigate the response of an ocean forced with normal year forcing (as in CORE-I) to a freshwater perturbation resulting from increased melt water run-off distributed around the Greenland coast. This experimental design, proposed by Gerdes *et al*. (2005, 2006), is motivated by possible increases in Greenland melt water that could occur as a result of anthropogenic global warming.

ACTION: CORE-related references should be placed on the WGOMD CORE webpage, including annotations (give references and comments to A. Pirani).

The CORE framework is not limited to these three experiments. There are discussions of a possible CORE-IV or more that could involve more coupling, for example through the use of a simplified atmospheric model (UVic, Speedy), and experiments investigating the response to anthropogenic climate change, for example looking at the sensitivity to increasing model resolution (response with or without eddies).

4.1.1. Problems of running ocean-ice experiments

- Diversity of methods:
  - Each group has favorite methods to get the models running.
  - Each group may choose to "tune" forcing to help their simulation, but some of these tunes are irrelevant or harmful to other models.
  - Each group defends their methods as reasonable and within error bars.
  - Many groups fail to document the details of their methods.
- Inconsistencies when decoupled:
  - Decoupling ocean-ice from interactive atmosphere-land exposes the simulations to spurious instabilities, largely related to ambiguities in how to specify the hydrological cycle (e.g., mixed boundary conditions and THC stability).
  - This problem leads to endless debates about SSS restoring.
  - These inconsistencies often do not cause problems until 100s of years.
- Ambiguities in forcing:
  - Ocean surface fluxes are poorly known.
  - Developing a global dataset for running ocean-ice models is very tough.
  - This is in contrast to the well known SST, making AMIP seem trivial compared to OMIP.

The question of whether CORE should remain as ocean-ice experiments or move to coupled experiments received considerable attention. On the one hand, running CORE-type experiments in a Hybrid Ocean Model Environment (HOME) would facilitate testing ocean parameterisations in a framework that is isolated from the sensitivities generated by running in coupled mode. On the other hand, there is the view that testing multiple ocean models in a HOME framework would be less beneficial than assessing the dominant atmospheric model limitations by testing the response to atmospheric models of increasing complexity.

An additional issue is the current funding priority on ocean biology, such as the climate impact of carbon and dimethylsulphide (DMS). Also, the current focus of the CORE experiments has been the current climate, but the question remains of whether CORE should include some idealised sensitivity experiments focused on rapid climate change.

ACTION: WGOMD needs to emphasise the limitations of CORE, such as the caution needed when interpreting the interior ocean. Metrics should be proposed to quantify errors due to drift.

4.2. CORE Atmospheric Dataset

- Large and Yeager (2004): Provide a balanced atmospheric state based on a hybrid of
  - NCEP reanalysis
  - Satellite products
  - "Adjustments"
- Normal year is based on statistical average of 50 year interannual data, plus sample synoptic variability.
- NCAR CCSM bulk formulae are used to compute fluxes based on prescribed atmospheric state and evolving SST and currents.
  - Differences in bulk formulae yield large differences in fluxes, which then corrupt comparisons.
- Many caveats come with Large and Yeager (2004), nonetheless WGOMD recommends its use for CORE as
  - It continues to be refined based on new data and input from the modelling community.
  - It is supported by two modelling centres (NCAR and GFDL).

It must be noted that river run-off is an annual mean. The IFM-GEOMAR group has considered alternatives (eg rivers from Roeske's MPI dataset), especially in the Arctic due to the sensitivity of the Atlantic MOC to freshwater coming from the Arctic.

4.2.1. Updates in the Large & Yeager CORE forcing dataset

As described by G. Danabasoglu, the CORE-II v.2 data set has been developed at NCAR that will be extended to 2006 by this December and will be available early 2008. The updates have addressed the issues raised during the 6th WGOMD meeting in Hobart 2005 (see Section 6.3 of meeting report - http://eprints.soton.ac.uk/41423/01/101_WGOMD6.pdf). CORE-II v.2 includes the following modifications:

- Extended through to 2006
- Wind speed correction based on QSCAT (2000-2004) (multiplied by a spatially varying factor that in general increases the wind speed everywhere and by up to 20% in the ACC)
- Wind direction adjustments (15° clockwise change in the central Equatorial Pacific, producing more cross-Equatorward flow, improving the curl in this convergence region. In most other regions the direction has changed by +/- 5°)
- Adjust specific humidity instead of relative humidity
- Short-wave down is lowered by 5% everywhere (not just +/- 30°)
- Albedo depends on latitude
- Bug corrections

Seasonal and/or interannual run-off variability will be included in future updates.

The data set for CORE-I v.2 will be developed based on CORE-II v.2 and will take into account the presence of sea-ice.

ACTION: WGOMD has agreed to continue working with the Large & Yeager CORE forcing, maintaining a close relationship with, and providing feedback to W. Large and colleagues at NCAR (All).

ACTION: Inform WGOMD when updated Large & Yeager dataset is available (A. Pirani).

4.3. Limitations of fixed surface boundary conditions and experience with EBMs coupled to ocean-ice models

R. Gerdes outlined some key limitations in running ocean-ice experiments uncoupled to the atmosphere due to the absence of key feedbacks, such as tropical wind stress feedback between the ocean state and atmospheric circulation, the feedback between atmospheric temperature and oceanic temperature advection and changes in sea ice extent, and the introduction of an unphysical feedback between the surface freshwater flux and SSS when SSS is restored.

Some initial experiments have been carried out with the UVic Intermediate Complexity Climate Model (ICCM) that consists of an OGCM, an EBM atmosphere with prescribed winds, sea ice, optional land-ice, a land surface and dynamic vegetation scheme and realistic topography/orography. One principal restriction of the use of EBMs is that they are tuned to present day climate, so their applicability for paleo-climate or climate change scenarios is doubtful. The UVic model was run with no SST or SSS restoring and no heat or freshwater flux corrections. This led to relatively large biases in temperature (exceeding 6°C both at the surface and at 100m depth) and salinity.

There are no simple solutions to the problem of proper surface boundary conditions for ocean-sea ice models. Mixed boundary conditions usually render the ocean circulation too sensitive and alternative coupling strategies have various associated problems. The use of energy balance models (EBMs) does not capture tropical interactions, may introduce biases, including the fact that EBMs are based on the present day climate. Atmospheric boundary layer models do not properly represent atmospheric transport. Empirical atmospheric models have difficulties with sea ice and cannot be trusted for sea surface states outside the observed range. A step forward could be the use of a combination of methods, such as the use of an EBM together with an empirical model or simple dynamical model to generate wind stress anomalies. Coupled or partially coupled ocean-atmosphere GCMs could be used to determine correct sensitivities (eg for CORE-II and CORE-III).

An issue that was raised by H. Banks is that the optimal ratio of ocean to atmosphere resolution remains to be established.

4.4. CORE-I

After being initially proposed in 2004, CORE-I has reached a critical mass with a community-wide proof of concept approval and seven ocean-ice models (see Table 1) that have been run for 500 years with the repeat 'normal year forcing' of Large and Yeager (2004). This is a significant step forward from 2005 when only three geopotential modelling groups were involved. The experiment is going far in being a comprehensive ocean model intercomparison exercise. The question now is whether PCMDI should be entrained so that a recommendation (not a requirement) can be made to the wider climate modelling community to run 500 year CORE-I experiments, submitting data to PCMDI.

ACTION: WGOMD should be making recommendations on data that should be saved, data format etc for the climate modelling community, by advising WGCM. For example, in eddy-permitting/resolving simulations, should correlations be saved?

Table 1: Models that have taken part in CORE-I

Model	Model release
NCAR-POP	POP1.4 and CSIM4
FSU-HYCOM	HYCOM 2.2 and CSIM4
GFDL-MOM	MOM4p0d
GFDL-HIM	HIM-Fortran M-release
KNMI-MICOM	MICOM 2.9
MPI	MPIOM 2.3
Kiel-ORCA	NEMO 1.06

The experiment has yielded a wide variety of results, with more questions raised than answered. Broad comparison projects such as this achieve much in this way by raising questions, which then motivate further research. Without such a comparison, questions would remain unasked, and thus unanswered. A peer-review paper with 24 authors (Griffies *et al*., 2008) is to be submitted to Ocean Modelling.

Follow-on research using the CORE-I approach has been given seed money from NSF for GFDL to coordinate a more tightly constrained CORE, largely in support of model development. This will involve a subset of models, each using the same grid as well as CCSM coupler and ice model.

4.4.1. Conclusions from 500yr CORE-I integrations

Many models performed similarly in tropics (though with notable outliers). Otherwise, there are major differences, which mainly point to differences in model configurations and algorithms. KNMI-MICOM is the clear outlier in all metrics. Perhaps this is because its resolution is too coarse, or perhaps it is the result of fundamental algorithm problems.

Some aspects of the pair of simulations NCAR-POP and FSU-HYCOM, as well as the pair GFDL-MOM and GFDL-HIM, are quite similar amongst themselves, though differ between. This difference highlights importance of ice component and details of ice albedo formulation (which differ between GFDL and CCSM). Figures 1 and 2 illustrate some important results from the CORE-I integrations on the simulation of the Atlantic thermohaline circulation. A stable meridional overturning circulation with a realistic transport strength and structure is important for maintaining a realistic ocean climate. Figure 1 shows the different behavior exhibited by different models, with some stabilizing relatively quickly (eg KNMI-MICOM, though to an extremely weak, almost absent overturning circulation) while others taking over 500 years to stabilize (GFDL-MOM, which was confirmed to have stabilized when the integration was extended to 600 years); and the GFDL-HIM simulation possess multi-centennial variability which is too long to assess with a 500 year run.

Figure 2 shows the global meridional overturning streamfunction averaged over model years 491-500. The FSU-HYCOM streamfunction has been interpolated to depth based coordinates, leading to noisy results. The GFDL-HIM and KNMI-MICOM streamfunction is kept on its native potential density coordinates and the figures are split into upper and lower plots to distinguish the Ekman-driven cells in the upper layer and the overturning cells in the deep ocean. The NADW cell is almost absent in the KNMI-MICOM simulation. All the z-level models have a realistic AABW cells of 5-10Sv, while the isopycnal models show much stronger overturning in the South.

Given the difficulties of establishing a stable climate simulation with reasonable biases using the MICOM code, KNMI investigators decided to transfer their efforts to the French geopotential model OPA, also represented by Kiel in the CORE-I study. This code conversion represents a major decision for the KNMI team, and is a nontrivial outcome of the CORE-I project.

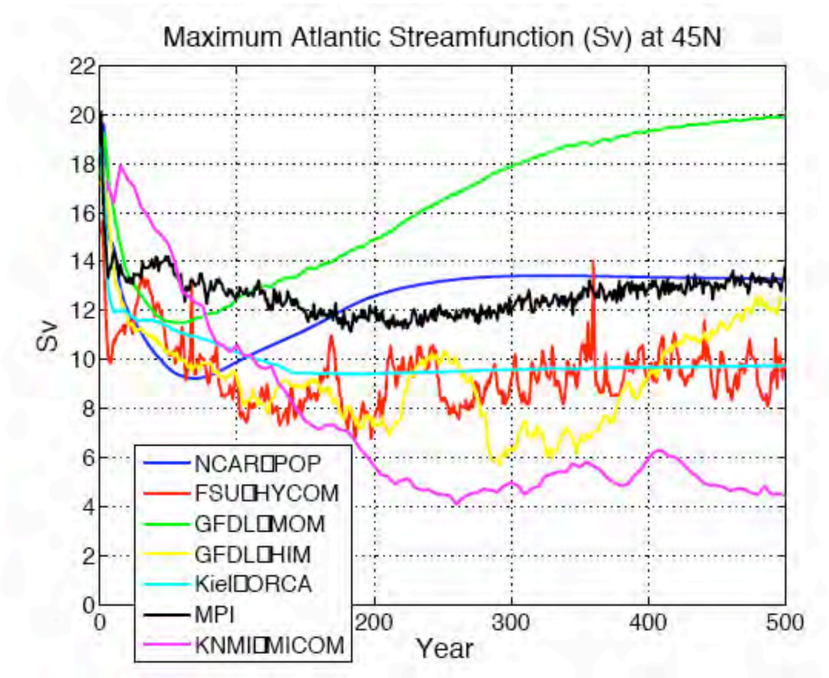

Figure 1: *Time series of the annual mean Atlantic meridional overturning streamfunction (Sv = $10^6 m^3 s^{-1}$). The index is computed as the maximum Atlantic MOC streamfunction at 45°N in the region beneath the Ekman layer (Griffies et al, 2008).*

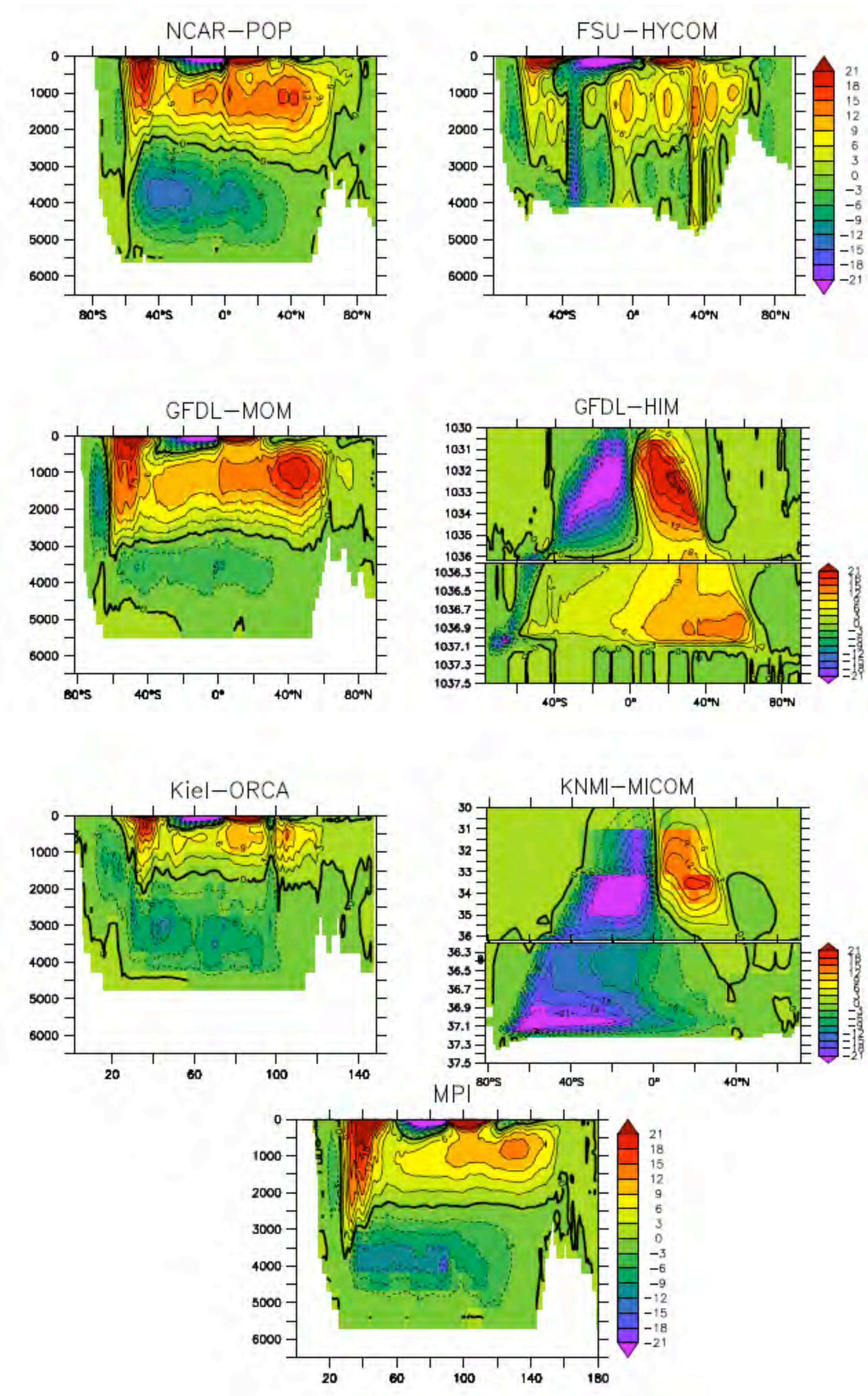

Figure 2: *The global meridional overturning streamfunction (Sv = $10^6 m^3 s^{-1}$), time averaged over the model years 491-500. The GFDL-HIM and NMI-MICOM results are plotted on the original potential density coordinates referenced to 2000db (1035-ϱ_{2000}) (Griffies et al, 2008).*

4.4.2. Salinity forcing and MOC Stability

Performing 500 year runs highlighted that the stability of Atlantic MOC was an issue for some models in CORE-I, causing the project to falter for many years. Some groups were not able to maintain a quasi-stable MOC for the CORE-I multi-centennial simulations without applying a non-trivial salinity restoring, also necessary to damp drifts in deep water mass properties. The participating groups were given the freedom to choose their own salinity restoring depending on each model's sensitivity. For example, CCSM maintained a globally weak salinity forcing with a piston velocity of 50m/4yrs; GFDL-MOM strengthened the restoring to 50m/300days; and KNMI and ORCA using stronger restoring in certain high latitude regions. Details are given in Table 2 and by Griffies *et al*. (2008).

model	flux	Piston velocity	Restoring region	Under ice	Normalized hydrology
NCAR-POP	salt	50m/4yrs	Global	yes	yes
FSU-HYCOM	salt	50m/4yrs	Global	yes	no
GFDL-MOM-A*	water	50m/4yrs	Global	no	yes
GFDL-MOM-B	water	50m/300days	Global	no	yes
GFDL-HIM	water	50m/300days	Global	yes	yes
KNMI-MICOM	salt	gradient (see caption)	regional	no	no
MPI-A	water	50m/4yrs	Global	fraction	yes
MPI-B*	water	50m/300days	Global	fraction	yes
Kiel-ORCA	water	50m/300days	regional	yes	no

** extra experiment to test sensitivity to salinity restoring (see Figure 1)*

Table 2: *Summary of choices made for the surface water/salt restoring in the CORE-I simulations (Griffies et al, 2008). The KNMI-MICOM simulations used a regionally varying piston velocity with zero in 35°N-65°N, 275°E-0°E (the North Atlantic); 50m/50days north of 75°N; 50m/30days south of 50°S; and 50m/1500days for the remainder. The restoring in the Kiel-ORCA simulation is high globally, except for in the Gulf Stream region where no freshening is allowed. Gradients between the different zones are linearly interpolated. The 'fraction' in column five indicates that the SSS restoring term was weighted by (1 – ice concentration) so that no restoring was applied with 100% ice. The sixth column refers to whether the (precipitation – evaporation + river runoff) flux was normalized to reduce drift.*

Some participating groups ran extra simulations to examine the sensitivity to the choice of salinity restoring. Figure 3 shows the annual mean volume transports across 45°N in the North Atlantic and across the Drake Passage for two MPI and GFDL-MOM simulation, one with weaker restoring (50m/4yr) and one with stronger restoring (50m/300days). The GFDL-MOM-A weak restoring simulation (left, black line) develops a series of growing amplitude multi-decadal oscillations after 250 year, demonstrating the need for multi-centennial simulations to evaluate the stability of the overturning circulation. This sensitivity led to the strong restoring experiment (GFDL-MOM-B) being chosen as the standard experiment that contributed to the CORE-I evaluation. The MPI model is less sensitive to the choice of salinity restoring. Even though the weaker restoring experiment (MPI-A) exhibited greater amplitude variability in the Drake Passage, this was the preferred experiment for the rest of the CORE-I evaluation.

Results from other additional Kiel-ORCA simulations indicate that the MOC solution is dependent on the drift in overflow density (not convection in the Labrador Sea). The drift in transport arises after about 200 years of integration and is related to a progressive freshening of intermediate waters in the Nordic Seas. This dependence will therefore be closely related to the choice of precipitation and river run-off, as well the choice of SSS restoring.

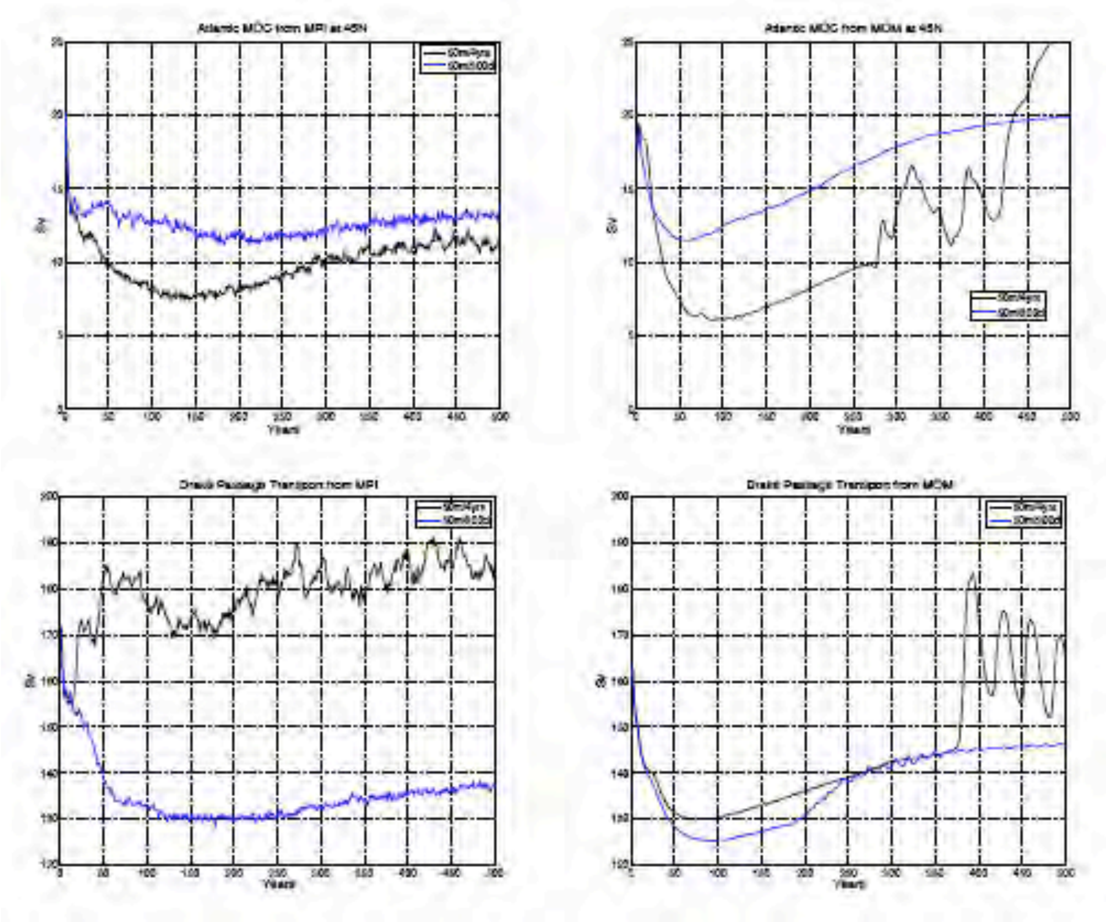

Figure 3: *Timeseries of the annual mean volume transports ($Sv=10^6$ m^3 s^{-1}) from two MPI (left) and two GFDL-MOM (right) simulations. The black lines are from ocean-ice (MPI-A and GFDL-MOM-A) simulations with a weak salinity restoring of 50m/4yr piston velocity and the blue lines are for simulations with a stronger salinity restoring of 50m/300days piston velocity (MPI-B and GFDL-MOM-B). The top panels show the maximum meridional overturning streamfunction at 45°N and the bottom panels show the eastward transport through the Drake Passage (Griffies et al, 2008)*

Hypotheses for model sensitivity to salinity forcing:

- The Large and Yeager (2004) dataset has overly strong precipitation in the Arctic and high latitude Atlantic..
- Annual mean river input over full year should be switched to more realistic seasonal cycle.
- Stable models (CCSM and MPI, with displaced pole placing fine resolution near Lab Sea) may resolve Atlantic currents better, reducing the ability of fresh Arctic water from halting the THC by advecting fresh water faster through convection regions.
- Weak SSS restoring places some models to one side of the mixed boundary condition instability, and other models to the other side.
- Full answer may be a combination of the above.

Initial results on the sensitivity of the MOC solution to model resolution indicate that models with a finer horizontal resolution (in the North Atlantic Ocean) are less sensitive to SSS restoring and can have a stable MOC with weak restoring. R. Greatbatch points out that the models are existing close to instability related to mixed boundary conditions. CORE-I experiments, perhaps initially of 200 years, could be run at different resolutions to test the robustness of the solutions.

In conclusion, the CORE-I results have highlighted the limitations of forcing ocean-ice models with a non-responsive atmosphere. This experimental setup led to an exaggeration of the effect of positive feedback mechanisms on the MOC prompting the use of stronger SSS restoring by most groups.

4.5. CORE-II

As H. Drange noted, a community effort with 20th Century hindcast simulations has the potential to uncover the formation, propagation and decay of dynamic and thermodynamic anomalies in the Atlantic-Arctic on decal to multi-decadal timescales, like the early warming (1920-1940) poleward of 60°N, which is comparable to present day warming but with a different atmospheric circulation and may be used to better understand future changes (external v. internal variability/adjustment). This has important implications for ecosystems and fisheries, that, for example, experienced a decrease in many stocks since the early warming and the 1960s and then a recovery since 1995.

WGOMD recommends that NCAR should be running ocean-ice experiments, not just ocean-only, though modelling priorities at NCAR are coupled runs, followed by ocean-only, followed by regional nests, then ocean-ice.

ACTION: CORE-II participants should provide details on the boundary conditions being applied, initialisation and the complexity of the ice model being used so that these details can be included on the WGOMD CORE webpage together with a table of participants, planned experiments and status (CORE-II participants to A. Pirani).

4.5.1. Ocean Initialisation

The initalisation of the CORE-II hindcast simulation is the key issue that needs to be addressed by the CORE-II protocol, particularly if more than the evolution of the upper ocean is to be analysed.

Models can be initiated sub-optimally from the existing reanalysis period starting in the 1950s and cycling though multiple times the simulation, though still having to ignore the analysis of the first 10 years of the final realisation because of adjustment. An additional limitation of this approach is that the existing reanalysis period is biased to the steady increase in the NAO index between the mid-1960s and mid-1990s.

Model drift, particularly below 400m can be removed by subtracting the trend from a climatologically forced control simulation, assuming that the system is linear.

Reconstructing 20th Century global hindcast forcing fields would be the ideal solution, but this is not a trivial task. The AWI group of R. Gerdes has statistically reconstructed atmospheric forcing fields for the Arctic Ocean (Kauker et al., JGR, under revision). The technique has earlier been applied to reconstruct atmospheric surface fields over the Baltic for the 20th century (Kauker and Meier, 2003). Extending this for the global ocean would take 2-3 years of dedicated effort. The statistical reconstruction involves the use of station observation data and the NCEP reanalysis, which captures the basic pattern in atmospheric state. SST (and sea ice) and SLP (NAO index) records can be used to reconstruct SST for the last century that can in turn be used to force an AGCM simultation to obtain surface forcing fields for spinning up an ocean simulation (R. Greatbatch). Reconstructing an internally consistent atmospheric reanalysis from observations would bring us closer to real conditions, compared to reconstructing forcing from AGCM simulations, so WGOMD should recommend and support a push to generate longer, consistent (dealing with inconsistency issues that can arise from the introduction of new observational products such as satellites) reconstructed 20th Century hindcast forcing fields (H. Drange).

ACTION: Provide details of Arctic reconstruction project (R. Gerdes and H. Drange)

4.5.2. Sea-ice Initialisation

G. Danabasoglu proposed a sea-ice initialization procedure that has been developed at NCAR by D. Bailey that is based on sea -ice fraction (IFRAC) data sets from either observations (SSM/I) or model output. The code will be easily available and portable and will compute IFRAC onto the target model grid. This procedure has been developed to provide a universal sea-ice initialisation procedure to replace starting simulations from zero or uniform ice thickness. Table 3 shows the variables used to derive January sea-ice thickness for the Northern and Southern Hemispheres and Figure 4 shows the corresponding sea-ice thickness field. The model handles differences between thickness categories linearly.

Field	N. Hemisphere	S. Hemisphere
Ice Fraction (IFRAC) [0-1]	SSM/I	SSM/I
Ice Thickness [m]	3*IFRAC	IFRAC
Snow Thickness [m]	IFRAC	IFRAC
Surface Temp (Ts) [^{o}C]	-18*IFRAC – 2	-3*IFRAC – 2
Internal Ice Energy [J]	Linear f(T_{si},T_{bot})	Linear f(T_{si},T_{bot})
Internal Snow Energy [J]	Linear f(T_s,T_{si})	Linear f(T_s,T_{si})

Table 3: *Initialisation of fields using a sea-ice fraction (IFRAC) data set for January. T_{bot} is -1.8^{o}C and T_{si} is the snow-ice interface temperature. All other fields (eg ice internal stress, ice strength, etc) are set to zero.*

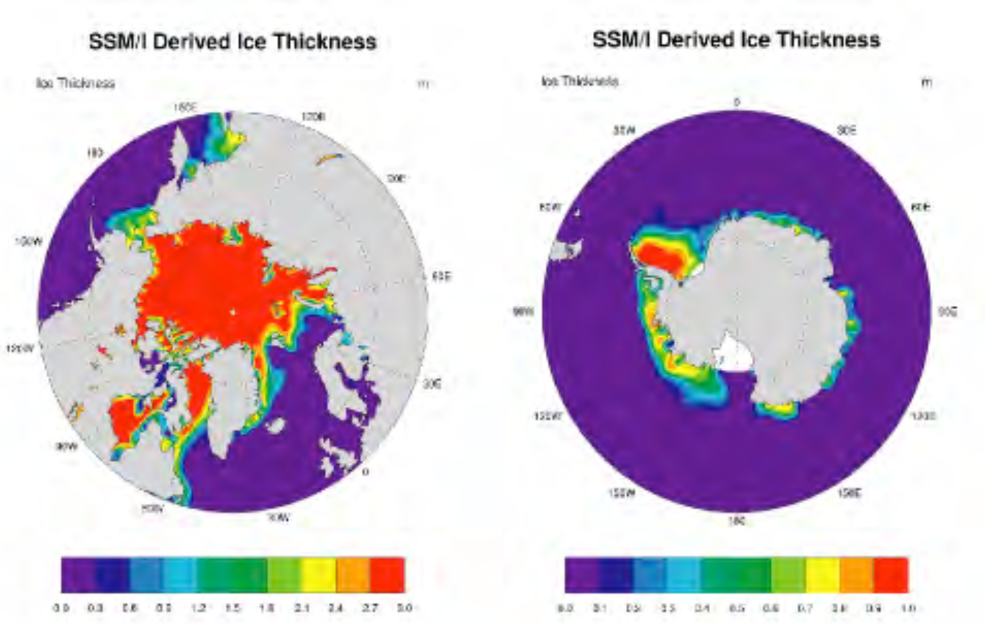

Figure 4: *SSM/I derived sea-ice thickness for January*

As shown in Figure 4, the sea-ice thickness depends on the IFRAC distribution. In regions of IFRAC=1, the thickness is 3m. This approach tries to approximate 'observed' ice volume in a simple way.

ACTION: Recommend that NCAR intialisation code should use a more realistic sea-ice distribution, and should correct for unrealistic ice volume off the coast of Siberia.

An alternative option for deriving sea-ice initial conditions would be to take climatological initial sea ice initial conditions, perform a 10 year simulation with a sea-ice model coupled to an ocean model, extract the final ice state and use this as the initial conditions (R. Gerdes).

4.5.3. Sensitivity to restoring

CORE-II simulations should be tested for the sensitivity to restoring conditions applied.

ACTION: Provide a paragraph on the alternatives to salinity restoring (H. Drange).

4.5.4. Proposal from the Pacific Implementation Panel

As presented by M. Balmaseda, there are large errors in GCM simulations of the Pacific basin and in the simulation of ENSO, as well as considerable uncertainty in the causes. The proposal presented to WGOMD suggests that, in addition to the main CORE-II experiments, a series of sensitivity experiments could be targeted at resolving the factors necessary to improve Pacific climate simulations. This could obviously also be extended to other ocean basins. The Pacific panel adds that a seasonal forecasting framework is an ideal

test bed to assess the quality of GCMs used in future climate projections.
There are known model deficiencies in the simulation of the Pacific climate, which include:

- Upwelling off the S. American coast
- Cold Tongue penetrating too far west
- Too weak /too strong east-west slope of the thermocline
- Equatorial heat content

The sensitivity experiments would aim to determine which are the dominant sources of uncertainty and error, for example:

- Forcing fields
- Bulk formula of air-sea interaction
- Model resolution
- Model parameterisation/configuration

The proposal suggests that a long CORE-II type ocean model simulation (50 years) is conducted with a variety of models forced by interannually varying atmospheric forcing such as the Large and Yeager (2004) dataset. This would act as a reference experiment and could provide the initial conditions for seasonal forecast-type experiments.

A subsequent subset of sensitivity experiments (a DRAKKAR-like study) could be carried out to test model sensitivity to the above listed possible sources of error and to see how models vary in sensitivity. The CLIVAR Global Synthesis and Observations Panel (GSOP) similarly aims to diagnose sources of uncertainty in different ocean synthesis products using:

- Analyses with different assimilation methods
- Analyses using different forcing fields
- Analyses with different models
- Models with different resolutions

This proposal suggests that the sensitivity experiments could be done and diagnosed by interested groups, without needing large transfers of data, and not all groups being obliged to carry out all the sensitivity experiments. It would be interesting to measure the sensitivities both in the mean state and in the interannual variability. Other CLIVAR basin panels may also be interested to join, giving WGOMD a good opportunity for interaction and feedback with other panels.

ACTION: Each CLIVAR basin panel should produce a list of questions and metrics to be tested in a CORE-II type experiment, including a view on the timescales of the processes that could be addressed by a 50-year experiment timeframe. Each panel should also name a panel member for liaison.

ACTION: Preliminary CORE-II results will be shown at the next Pacific Implementation Panel meeting on 29-30 November 2007, Guangzhou, China (C. Böning)

4.6. CORE-III

The proposal to run a freshwater perturbation experiment in the CORE framework continues to be endorsed by WGOMD. Figure 5 shows the hosing perturbation of 0.1Sv put forward by Gerdes et al (2006) that would represent an increase in melt water input from Greenland. This is in contrast to the unrealistic historical practice of applying a freshwater perturbation uniformly over a North Atlantic box. It is argued that a more realistic distribution of a water flux anomaly relative to the pathways of the North Atlantic meridional overturning circulation is important for the transient response of the ocean. The proposed perturbation is slightly stronger than the average increase in meltwater flux from Greenland estimated over the next 500 years (Huybrechts and Wolde, 1999) and it is kept constant during the 100 year experiment, which is unlikely to be the case in reality.

The experiment would be spun up with CORE-I normal year forcing, with the last 100 years repeated with the freshwater perturbation. Continuing the simulation for a recovery period would be optional. The choice of surface boundary condition remains open and could be coupled or partially-coupled, for example by an anomaly-EBM. WGOMD members are interested in exploring the CORE-III design.

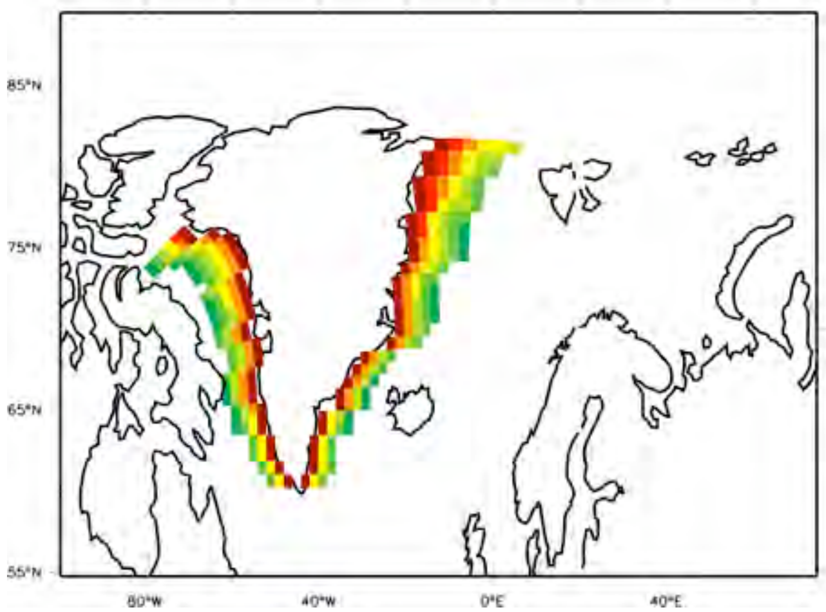

Figure 5: *Distribution of surface freshwater flux anomaly (from Gerdes et al 2006).*

ACTION: To prepare references and information relevant to the CORE-III experiment for the WGOMD webpage (R. Gerdes).

5. Ocean Model Evaluation

The fourth term of reference of WGOMD states that one of the responsibilities of this working group is "to stimulate the validation of ocean models when used in stand alone mode and as part of a coupled ocean-atmosphere model, using oceanographic data and other methods." There is a need for a community-wide standardised method for the overall comparison and evaluation of models that is not solely based on 'favorable' diagnostics.

5.1. Coupled model evaluation at the Met Office Hadley Centre

H. Banks gave an overview of the approach being adopted by the Met Office Hadley Centre for the objective and thorough evaluation of HadGEM3 coupled model. Historically, the analysis of previous generations of the coupled model has been somewhat ad-hoc, focusing on certain metrics such as top of the atmosphere (TOA) balance, SST drift and heat transports. Since the development of HadGEM (1-3), metrics have been increasingly used, initially being used as a basis of model performance acceptance criteria (scientific credibility, eg conservation of mass, energy, water; scientific benchmarks for the ocean) to being used as an integral part of the model development. The Climate Prediction Index (CPI) (Johns *et al*, 2006), shown in Figure 6, has been used since HadGEM1, where multiple weighted non-dimensional indices of root-mean-square errors compared to present-day climatological mean fields are plotted on one bar chart to give a comprehensive overall view of model performance.

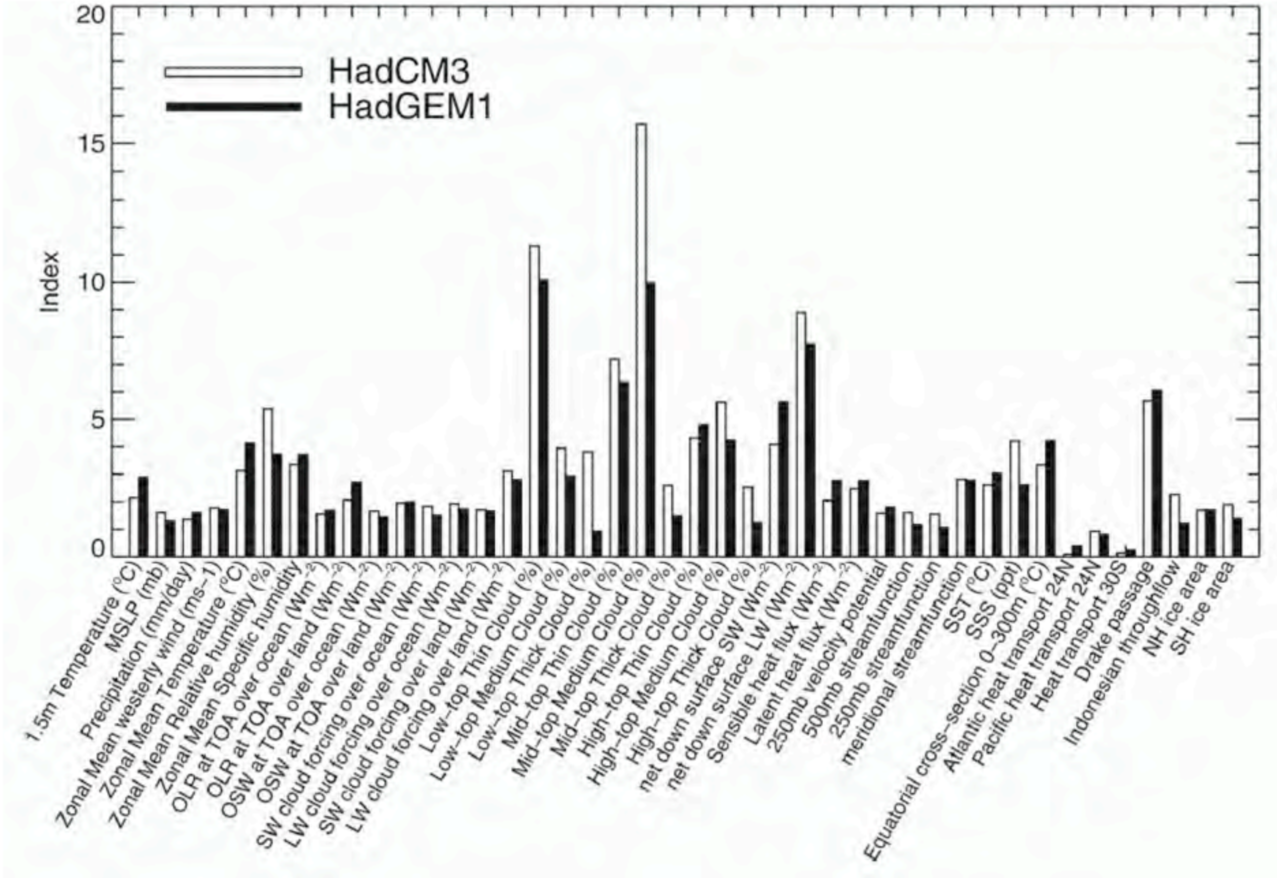

Figure 6: *Comparison of a non-dimensional index of model skill compared with observed climatological fields between HadCM3 (open bars) and HadGEM1 (filled bars). RMS errors are normalized by the spatial average of internal climate variability estimated from HadCM3's control run for each variable shown, larger normalized RMS errors being represented by longer bars. The model data comprise averages of a 20-yr period early in the third century of the HadGEM1 control simulation (referenced to the start of the spinup) and a corresponding period of the HadCM3 control.*

HadGEM3 is now being developed with assessment grouped into conservation, global circulation, regional variability, and seasonal to decadal variability/prediction. A set of metrics is being defined that will provide the framework to objectively define the overall view of the assessment. These metrics are, as far as possible, metrics that are used community-wide and are generally not new. The assessment will be done against observations or, in the absence of observations, other IPCC models. The initial suggestions for sea-ice and ocean variables, listed in Table 4, that are to be assessed are of particular relevance to WGOMD ocean-ice experiments.

There are certain issues related to the ocean assessment that need to be considered, such as:

- Model drift, particularly in terms of reliably assessing the T-S properties of water masses, such as knowing the longer term drift to assess short term runs and knowing what are the long term impacts of drift
- The use of neutral densities in observational estimates, which are not easily applied to models
- How to combine a large number of metrics into an easily 'digestible' assessment, for example by using skill scores. Taylor diagrams are an option .

Sea-ice variables	Ocean variables
March/Sept. NH/SN ice extent and area	Temperature (SST, X-sections/collocations)
Month of max/min NH/SH ice extent	Salinity (SSS, X sections/collocations
Seasonal amplitude of NH/SH ice extent	Mixed layer
RMS difference of winter ice concentration	Currents (EUC, ACC, Arctic transports)
Ice extent in certain regions	Upwelling (Equatorial, basin upwelling)
RMS of central Arctic ice thickness	Ocean transports (heat, freshwater)
Gradient of Arctic ice thickness	Water masses (T-S, formation)
Maximum of ice thickness in NH/SH	Budgets (conservation, surface fluxes)
RMS ice speed in NH/SH winter	MOC (overflows, transports, etc.)
Transport across selected Straits	SSH (mean, anomaly)
Annual mean northward ice transport in SH	Mesoscale features (eddy KE, TIWs, Gulf Stream separation, Agulhas)

Table 4: *Initial suggestions for sea-ice and ocean variables to be assessed in HadGEM3*

ACTION: To identify what data sets are being used by the Met Office Hadley Centre to assess the ocean and sea-ice components of HadGEM3 and how the metrics proposed by the Met Office Hadley Centre compare with the metrics GSOP is considering (H. Banks)

ACTION: WGOMD needs to input to WGCM an ocean-ice model view of how climate models are assessed (WGOMD)

5.2. Overview of the CLIVAR Global Synthesis and Observations Panel (GSOP) activities in defining and coordinating ocean indices

As described by D. Stammer, the GSOP is leading the development of a CLIVAR/GODAE Global Synthesis Evaluation Framework to determine in a quantitative way the skill, usefulness and limitations of existing synthesis approaches for CLIVAR's climate research, where reference data sets are to be used as the basis for a systematic model-data comparison. This framework will also help define the climate observational data standards required for CLIVAR syntheses, as well as setting out recommendations with regards to future synthesis resource planning. The evaluation effort will be based on synthesis results available from the period 1950 to present and will include the TOPEX-JASON-1 era.

The overall goals of the inter-comparison of global synthesis efforts are to:

- Evaluate the quality and skill of available global synthesis products and determine their usefulness for CLIVAR.
- Identify the common strength and weakness of these systems and the differences among them, as well as to identify what application can be best served by what synthesis approach.
- Define climate-indices and diagnostic quantities that should be produced on a regular basis by each synthesis effort to support regional and global CLIVAR analyses and process studies.
- Define and test climate-relevant indices that in the future should be provided routinely by ongoing or planned synthesis efforts in support of the wider community.

According to its nature, the synthesis evaluation effort will have its primary focus on basinscale and global quantities such as global upper-ocean heat content, global meridional overturning transport stream function and meridional heat transport. Important regional climate-relevant processes relevant for CLIVAR’s basin studies will also be addressed. GSOP has solicited input from the CLIVAR regional panels to identify relevant metrics and reference data sets. To perform the evaluation work, individual synthesis efforts will be asked to compute integral quantities (e.g., transports) and climate-relevant indices from their results and make them available to the project for further evaluation.

The intercomparison quantities, which will be further refined from the feedback given by the CLIVAR basin panels, including the discussion leads are the following (*a more detailed list is given in Appendix C*):

1. RMS Model-Data Misfits (P. Heimbach)
2. Meridional Transports (A. Koehl)

3. Change in Sea Level, Heat and Salt Content (M. Alonso Balmaseda; A. Weaver)
4. Transports through Key Regions (T. Lee)
5. Water Masses (Keith Haines and T. Lee)
6. Indices (A. Fischer)
7. Surface Fluxes (L. Yu)

Determining where models are not fitting observations will help resolve particular model deficiencies, for example by going towards an internal parameter estimate of mixing. Figure 7 shows an example of such an intercomparison, in this case of transports (the difference between Bermuda and Labrador basin transports) produced by different synthesis products (coloured lines) and observations (black line)

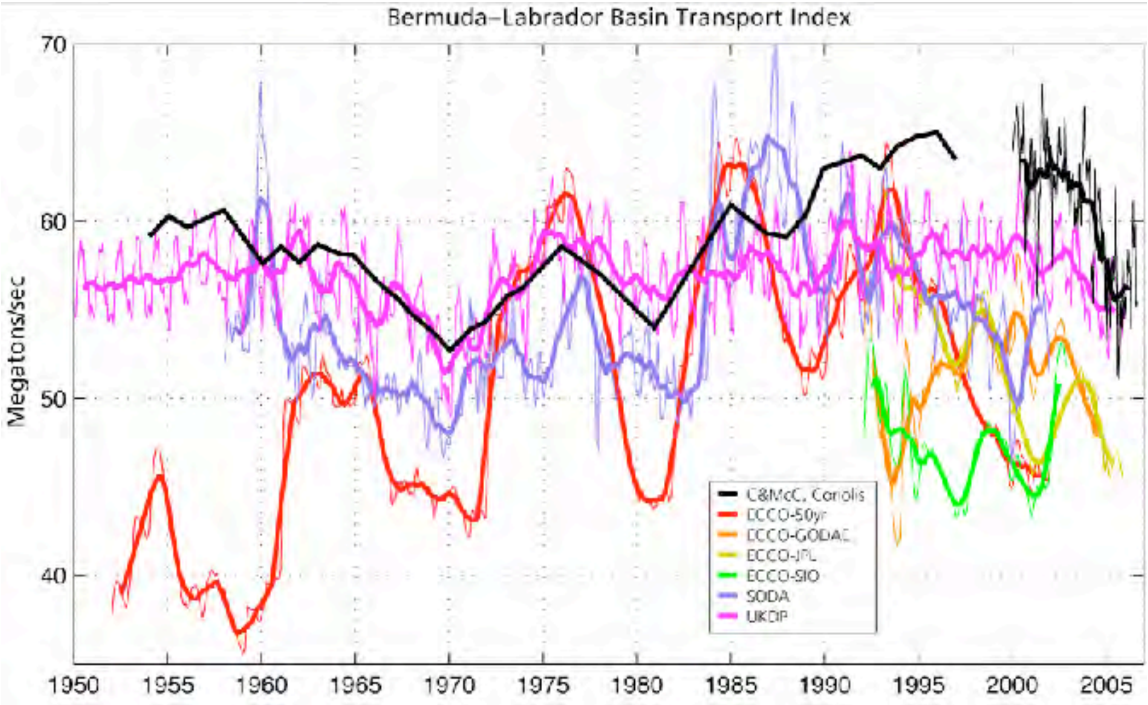

Figure 7: *Bermuda-Labrador Basin Transport Index*

GSOP requests input from WGOMD on the following:

- The model standards, such as the use of state of the art parameterisations that the synthesis community should use. In response, WGOMD recommends that the WGOMD review paper (Griffies *et al*., 2000) is still relevant in terms of what the minimum requirements are for a reputable ocean model.
- What forcing standards should be used, for example whether a particular bulk formula should be used. The synthesis community intends to produce a reference flux data set against which estimates of surface fluxes can be evaluated.
- What data sets are required from the CLIVAR Data Assembly Centres (DACs: http://www.clivar.org/data/dacs.php) for model evaluation.

ACTION: Provide input to GSOP (D. Stammer) on the above issues for the synthesis evaluation document that is in preparation (S. Griffies)

ACTION: Circulate GSOP draft synthesis evaluation document to WGOMD (A. Pirani)

5.3. WGOMD Repository for the Evaluation of Ocean Simulations (REOS)

WGOMD will develop a website hosting a peer-reviewed clearing house on how ocean models can be systematically assessed with respect to observed datasets to monitor simulation skill, characterize the structure of model biases, assess the impact of numerical/physical choices and guide further investigations. The website will share methods, views on best practices and observational dataset quality with the wider ocean modelling and data assimilation community. Different modelling groups already have extensive model evaluation practices and experience with comparing model simulations to observed data. The Met Office Hadley Centre, for example, has quality controlled the WOCE profiles database and is in the initial stages for extending this to ARGO data (http://hadobs.metoffice.com/). The data synthesis community is also in the process of organizing the evaluation of synthesis products, as described previously in Section 5.2. The activity proposed by WGOMD will help to organize information and access to these resources.

Metrics can only be defined as being useful if they are relevant for application, for example, as benchmarks to compare model development or to help understand ocean variability and mechanisms in models. There are different requirements depending on the focus of the assessment. Metrics will be classified according to priority and complexity. Metrics need to be adaptable to cope with differences that arise from analyzing different model resolutions, such as calculating transports through straits in models with different degrees of resolution. Quantitative methods (space-time collocation, filtering, statistical analyses, etc.), such as the methods being developed as part of the DRAKKAR consortium (Penduff et al, 2007), will be identified.

The recommended model assessment would ideally could become a community-wide automatic process. At NCAR, for example, an automatic comparison is carried out with observations of timeseries, surface fluxes compared to the Large and Yeager dataset (2004), and model sections compared to WOCE data. Ideally, model validation against observations should not just be a direct comparison with data, but also with derived products that are tied to specific processes, for example. Comparisons of T-S profiles should be extended to assess water mass volume and heat transports. Such products are not as clear cut as direct comparisons with data, but they are often more important to diagnose why models differ from observational data.

ACTION: Summarize observational data quality control activities at the Met Office Hadley Centre (H. Banks)

ACTION: What are the official GODAE metrics? Have class I-IV metrics with all the data on the same grid for all the models for the Atlantic. This needs to be extended globally (E. Chassignet)

ACTION: Feedback and input on ideas for developing a webpage for evaluating ocean models, making recommendations for data saving and a classification of metrics (All to A. Pirani and S. Griffies)

6. WGOMD Recommendations to WGCM

Ocean model data currently has to be converted to a regular spherical coordinate grid for to be part of the IPCC archive at PCMDI. While this may facilitate some aspects of model-intercomparison and is not a problem for scalar quantities, vector and transport quantities should be kept on the original model. The model output should be saved both on the original grid and the regular grid, but this leads to problems due to limitations in storage capacity and PCMDI currently does not support storage on the original model grid. A way around this would be for certain diagnostics to be computed online but this would have to be decided before the running the integration. It would also be costly to repeat integrations to calculate newly developed diagnostics.

ACTION: WGOMD needs to recommend what ocean data needs to be saved in the next IPCC assessment process (all), and work towards formulating what should constitute the basis for the assessment of climate models (S. Griffies, H. Banks) and regional models (E. Chassignet).

ACTION: WGOMD strongly recommends to PCMDI that native ocean grids be supported.

ACTION: Tools for converting between grids (eg those available at NCAR) should be shared.

ACTION: WGOMD recommends that participants to a future AR5 submit a 500 year CORE-I simulation as well as CORE-II, depending on progress.

7. Summary of Workshop on Numerical Methods in Ocean Models

Prior to the WGOMD panel meeting, the WGOMD, with assistance from the Layered Ocean Model (LOM) group, organized the "CLIVAR WGOMD Workshop on Numerical Methods in Ocean Models" on August 23-24, 2007 in Bergen, Norway.

The evolution of ocean models is prompted by a growing range of high profile scientific and engineering applications. These applications range from refined resolution coastal and regional modelling forecast systems, to centennial-millenial global earth system models projecting future climate. Groups worldwide are working to improve the integrity of ocean models for use as tools for science research and engineering applications. This work involves a significant number of fundamental questions, such as what equations to solve, which coordinate system to solve the equations, what horizontal and vertical mesh is appropriate, what physical parameterizations are required, and what numerical algorithms allow for computational efficiency without sacrificing scientific integrity. Furthermore, given the increasing size of many applications, as well as difficulties of doing everything in just one group, there is a growing level of collaboration between diverse groups. This collaboration spans the spectrum of algorithm sharing to the merger of previously disparate code bases.

The numerical methods workshop aimed to foster the maturation of ocean models by supporting enhanced collaboration between model developers. It did so by bringing together nearly 100 of the world's top ocean model developers and theoreticians. Presentations were given throughout each day, with plenty of opportunity for interactions, debate, and networking. The workshop emphasis was on fundamentals of design and numerical methods, with relevance of a particular approach gauged by its ability to satisfy the needs of various applications. This workshop provided a venue for participants to educate one another on the latest advances in ocean model development.

A workshop report is available (CLIVAR Publication Series no. is 128/WCRP No. 4), with the summaries of the following sessions prepared by the respective session Chairs:

1. Overview of equations and methods: Alistair Adcroft (GFDL, Princeton University)
2. Vertical coordinates: Robert Hallberg (GFDL)
3. Non-rectangular structured meshes and unstructured meshes: Todd Ringler (Los Alamos National Laboratory), Matthew Piggott (Imperial College), Laurent White (GFDL)
4. Parameterization of physical process: Richard Greatbatch (IFM-GEOMAR) and Martin Schmidt (Baltic Sea Research Institute)
5. Coastal/Regional modelling: Eric Blayo (Laboratoire Jean Kuntzmann, Universite Joseph Fourier), Jarle Berntsen (University of Bergen)
6. Basin and Global Models: Claus Böning (IFM-GEOMAR), Anne Marie Treguier (IFREMER) and Stephen Griffies (GFDL)
7. Ocean processes and inverse methods: Detlef Stammer (University of Hamburg)

The talks can be downloaded from the Workshop webpage at http://www.clivar.org/organization/wgomd/nmw/nmw_main.php.

This is the third scientific workshop organized by the WGOMD, with the first being June 2004 in Princeton USA ("State of the Art in Ocean Climate Modelling") and second begin Nov 2005 in Hobart, Australia ("Southern Ocean Modelling"). Each workshop was received very positively by the international ocean modelling community. We thus plan to continue coordinating WGOMD panel meetings with scientific workshops. This coordination is also motivated by the CLIVAR SSG, noting that reduced funding requires panel meetings to be held along with workshops to provide added financial support for travel costs of panel members.

8. WGOMD Future Direction

WGOMD has previously mainly been concerned with the *science of ocean models*. It now needs to go towards the *science of ocean modelling*, including topics such as decadal prediction (assimilation, initialisation), high resolution models. WGOMD needs to support WGCM in the understanding climate change response, while also supporting the regional basin panels.

The WGOMD vision is being expanded to include ocean modeling requirements for decadal prediction. With work taking place at the Hadley Centre and NCAR H. Banks and G. Danabasoglu can represent these requirements. The separation between ocean data assimilation and WGOMD remains but strong links will continue to be maintained with GSOP. WGOMD needs to widen its mission to include regional modelling, operational modelling and biogeochemical ocean modelling. WGOMD has not had a strong presence within the WCRP Working Group on Numerical Experimentation (WGNE), despite having expertise to contribute, particularly in terms of setting model standards for decadal prediction, ocean data assimilation, regional modelling and modelling biogeochemical cycles.

8.1. Membership
H. Banks has been nominated to become WGOMD co-chair and G. Danabasoglu has been nominated to join WGOMD. To be confirmed by SSG.

A. M. Treguier, C. Böning, R. Gerdes and E. Chassignet have rotated off WGOMD but will remain active participants in WGOMD activities, unofficially assuming 'Emeritus' status.

WGOMD will consider recommending a new member based on expertise (not just geographical representation), for example from the biogeochemical modelling community.

8.2. Next Meeting
The 8th WGOMD session is planned for the 27th-30th April 2009 at the Hadley Centre, Exeter, UK.

8.3. Next Workshop
A science workshop is proposed to coincide with the next WGOMD panel meeting in Exeter, UK at the end of April 2009: "Representing and parameterising the ocean mesoscale: 20 years after Gent and McWilliams (1990)"

ACTION: Start planning content and invited talks, logistics and sources of funding for the proposed workshop (H. Banks, S. Griffies, A. Pirani).

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Appendix A

Attendees of the 7th Session of CLIVAR WGOMD

Panel Members
Stephen Griffies (Chair)
Helene Banks
Gurvan Madec
Helge Drange
Richard Greatbatch
E. Chassignet
Hiroyuki Tsujino
Rüdiger Gerdes
Claus Böning
Anne-Marie Treguier

Guests and Observers
Magdalena Alonso Balmaseda
Detlef Stammer
Siobhan O'Farrell
Gokhan Danabasoglu (in the place of M. Holland)

ICPO
Anna Pirani

Panel Members not present
Matthew England
Marika Holland

Appendix B

Agenda of the 7th Session of CLIVAR WGOMD

Friday 24th August
Dinner meeting with WGOMD members

Discuss agenda (panel)
Discuss numerical methods workshop (panel)

Saturday 25th August
WGOMD panel meeting 08:00-11:00

Introduction to the Panel Meeting (Griffies)
CORE Briefing to WGOMD (Griffies)
CORE-I manuscript
CORE-I extensions (strongly constrained CORE-I at GFDL)
CORE-II, CORE-III and CORE-IV
Reports CLIVAR basin panels
Pacific (Balmaseda)
Atlantic (Böning)
Indian (Pirani)

Break

WGOMD and SOPHOCLES joint 11:15-13:15

Southern Ocean and Cryosphere
Southern ocean panel (O'Farrell - material from Speer and Rintoul)
Southern ocean in IPCC AR4 models (Russell/Konig)
Ice shelf ocean interaction (Smedsrud/Assmann)
Clic (Lytle)
Discussion of future links between CliC and WGOMD (O'Farrell)
Cryosphere issues for AR5 simulations (O'Farrell)

Lunch

WGOMD and SOPHOCLES joint 14:15-17:30

Coordinated Ocean-ice Reference Experiments (CORE)
Briefing to SOPHOCLES (Griffies)
Updates of the Large & Yeager forcing dataset (Danabasoglu)
Comparison of reanalysis based products with observations over sea ice at BAS (O'Farrell)
Issues of hindcast experiments with inter-annually varying forcing (Böning)
Experience with EBMs and ice ocean modelling (England and Gerdes)
Discussion on a future Southern ocean focused CORE experiment, how well did CORE 1 and CORE II model the ice-ocean interaction? (O'Farrell)

Break & Group Photo

Arctic Ocean Model Intercomparison Project (AOMIP) (Gerdes)
Developing a Repository for Evaluating Ocean Simulations (REOS)
Metrics and methods for evaluating ocean-ice simulations (Griffies, Banks)
Input from reanalysis projects (Stammer)
Discussion on assimilation of data from IPY projects into models (Schodlok)
SOPHOCLES Discussion, plans for sunday meeting

Sunday 26th August
WGOMD Panel Business 08:30-12:00

Panel member reports
WGOMD: history and future (Griffies)
Membership
Action items (Pirani)

Appendix C

CLIVAR-GODAE Synthesis Intercomparison Framework Quantities for Intercomparison

1. RMS Model-Data Misfits (Discussion Lead: Patrick Heimbach):
   - Difference from WOA01 climatological (monthly, Jan.-Dec.) potential T & S
   - RMS misfit from Reynolds SST
   - RMS misfit from in-situ T & S profiles (including XBT, CTD, Argo, moorings)
   - RMS misfit from altimeter-derived SSH
   - RMS misfit from tide-gauge SSH

2. Meridional Transports (Discussion Lead: Armin Koehl):
   - Timeseries of meridional MOC of the global ocean, Atlantic and Indo-Pacific as a function of latitude and depth and for the global ocean as a function of latitude and potential density.
   - Timeseries of meridional heat and freshwater transports of the global ocean, Atlantic, and Indo-Pacific as a function of latitude.
   - Time series of maximum MOC strength and heat transport at 25N, 48N in North Atlantic

3. Change in Sea Level, Heat and Salt Content (Discussion Leads: Magdalena Alonso Balmaseda; Anthony Weaver):
   - Monthly means of averaged temperature (proxy to heat content) and salinity over the upper 300m/750m and 3000m.
   - Time series for spatial averages within a list of 30 pre-defined boxes in various parts of the ocean.
   - Monthly means of sea level, and optionally steric height and/or bottom pressure.
   - Time series for spatial averages within a list of 30 pre-defined boxes in various parts of the ocean.

4. Transports through Key Regions (Discussion Lead: Tong Lee):
   - Indonesian Throughflow volume transport
   - ACC volume transport through the Drake passage.
   - Florida Strait volume transport, temperature flux, and salinity flux.

5. Water Masses (Discussion Leads: Keith Haines and Tong Lee):
   - 18-C water volume in the N Atlantic Ocean, volume-weighted average salinity of the 18C water as a function of month.
   - Annual Maximum mixed layer depth within the Labrador sea and the T,S properties of that mixed layer.
   - Warm-water volume in the equatorial Pacific (5S-5N, 120E-80W) AND tropical Pacific (20S-20N, 120E-80W),
   - Depth of 20 degree isotherm in Pacific Ocean as a function of longitude, latitude, and month.

6. Indices (Discussion Lead: Albert Fischer):
   - Sea surface temperature anomaly indices averaged over lat-lon boxes in the ocean. Here are the indices:
     - Pacific: Nino1+2; Nino3; Nino3.4; Nino4
     - Indian: SETIO; WTIO
     - N. Atlantic: Curry and McCartney transport index.

7. Surface Fluxes (Discussion Lead: Lisan Yu):
   - Monthly means of net surface heat and freshwater flux as function of geographic location.
   - Time mean of net surface heat flux and freshwater flux over entire model domain.
   - Zonal averages of annual mean net surface heat flux and freshwater flux over the model domain.

Appendix D

SOPHOCLES- Southern Ocean Physical Oceanography and Cryospheric Linkages.

Introduction

SOPHOCLES is a new project focussed on how well the current generation of models represent the interaction between the Cryosphere and the Southern Ocean. The first aim is to verify these models against the latest available observations and use the observations to constrain choice of parameterisations used by different groups. Many Cryospheric interactions are not represented or need different parameters to best represent the properties of Southern ocean sea ice. The project will aim to develop new parameterisations of these processes for use in global models or direct inclusion of these processes in regional focussed studies. Another key question this study hopes to address is why the observations show less sensitivity of southern ocean sea ice to the climate signal than in the Arctic, and less sensitivity than the models indicate. Have we correctly represented the response of the cryosphere to increasing temperatures due to climate change, can we improve our certainty of the climate sensitivity of the cryospheric ocean interaction. The plan is for this project to be part of the Marine Cryosphere Theme of Clic, with close links to over related projects/panels in CLIVAR and SCAR.

Background

The Southern Ocean is crucial region of the worlds ocean to model correctly, it a major sink of heat and CO_2 it connects the 3 major ocean basins and a major link in the ocean conveyor belt through transport of heat and salt in the ACC. The southern ocean is the source regions of major ocean water masses, AABW, AAIW, SAMW that are exported due to the mid latitudes and tropics at depth.
Hence the ability of ocean models to correctly represent the formation transformation and transport of these water masses is a strong test of model performances. This test relies on accurate representation of sub grid scale process, mixing by eddies diapycnal mixing convection, downslope flows off the Antarctic continental shelf.

The Cryospheric components that are included in the project are the sea ice cover, the ice shelves, icebergs and the ice on the continental fringe that is in contact with the ice such as in glacier tongues or parts of the West Antarctic Ice sheet that are allow the ocean to flow underneath for example at Pine Island Glacier.

The sea ice is the best studied on this list and full thermodynamic and dynamic representations of the ice including rheology has now been included in the majority if the models used in the recent AR4 IPCC Assessment process. Whilst these ice processes are now included in the global models it is not clear at coarse resolution how well they can capture the key processes with in the inhomogeneous ice pack, such as representing regions of short term local divergence and polynyas where the majority of new ice will be formed, the shearing of ice driven by wind currents and internal dynamic and the ridging and rafting processes. The ice models performance need to be compared with each other and with regional processes studies such as those that have occurred in the Weddell and Bellingshausen Seas and new experiments during IPY.
The inclusion of the circulation under ice shelves, the forming and modifying of ice shelf water and the freshwater fluxes from glacial ice and icebergs are new focus for this project, they are currently niche areas with few researchers examining aspects of these process in both observational and regional modelling studies (e.g. ISOMIP). The aim of the project will be to build on these existing studies, extend the regional modelling efforts, develop and test parameterisations that include the sensitivity of these processes that can be taken up by the broader ocean/climate community. Whilst there is interest in the ocean community particularly the sea level community in glaciological aspects of the ice shelves particularly in relation to changes to the grounding line and ice stream flow as ice shelves thin, we expect this to be studied under the Ice sheet and sea level CliC theme.

Southern ocean is understudied relative to other regions

The Southern ocean despite increased interest in the last decade since WOCE is an understudied/data sparse part of the world's oceans. The Southern Ocean was the last region to be populated by an ARGO array due to its vastness and less ship activity. There have been more major international programmes focussed in the Arctic such as ACSYS, the Arctic Flux study and the EU's current DAMOCLES project. By comparison in the Southern ocean there is the Clivar/CliC/SCAR Southern ocean implementation panel which co-ordinates across a range of activities and the SCAR/SCOR Southern ocean group that includes physical and biogeochemical observations. This suggests that it is timely to have an additional group focussed on Southern ocean modelling, linking the model processes to the observational projects and integrating improved understanding obtained through observational, process and modelling studies in the next generation of models.

Seamless approach across different time scales.

SOPHOCLES aligns with the WCRP COPES (Co-ordinated Observation and Prediction and of the Earth System) strategy, as it involves using observations to improve our ability to model the ocean-cryosphere system across a range of time scales. The same models and parameterisations should be utilized through short term sea ice forecasting (1week) through climate variability (seasonal to decadal) to climate change (multi-decadal to centennial). There is however some uncertainties if all ocean cryospheric process can truly use seamless models.

Short term sea ice forecasting needs to allow more accurately for effects of tides and inertial response of the ice and more accurate solvers for the rheology to represent the ice cover at high temporal and spatial resolution. Unlike in the Arctic where the snow cover and ice cover has implications for seasonal forecast over the adjacent continents, it is not clear that Southern ocean sea ice and ocean variability has an impact on seasonal forecasting across the Southern Hemisphere continents, which seasonal to interannual variability is dominated by ENSO and to a lesser extent SAM. There is some statistical skill in the Weddell Sea ice extent due to the Antarctic Dipole which is manifestation of the La Nina signal in the region. There also some studies at an early stage (in Brazil and Argentina) linking sea ice extent in Weddell sea with winter climate anomalies in South America, and also some weak evidence of coherent ice anomalies with SW Western Australian climate. However, the ice is probably a passive tracer rather than the driver of these anomalies with large scale atmospheric teleconnections from SAM and ENSO the most probable cause of correlations.
Investigations on wether the Southern ice-ocean system is a predictable source of decadal variability are at an early stage, though global assessments suggest that is with strongest coherence in the Ross and Weddell seas the sources of the southern limb of the thermohaline circulation. Also, the deep mixed layers of the mid-latitude Southern ocean means that anomalies can persist at depth and be advected with the ACC. The sea ice cover is influenced by ENSO and depending on the teleconnection route can lead the strongest equatorial temperature anomalies in some ice sectors. Sea ice anomalies in ice concentration and thickness around the Antarctic can persist for several seasons in the observations but the implications for broader climate predictability has yet to be fully explored.

Whilst the aim is to use the same model parameterisations out to centennial time scales, we have to recognise that the parameterisations have been built around present day conditions; there may be non-linearities in the system, e.g. changes introduced by a declining strength in the Southern ocean limb of the thermohaline circulation that we have not anticipated. A second area of uncertainty from non-linearities at longer time scales is the glaciological response of the ice shelves to warmer temperatures. The warming due to high end emissions scenarios for CO_2 over the next century could lead us to a more rapid glaciological response an issue recognised in the uncertainties in the glaciological input to sea level predictions from the in the IPCC AR4.

New Observational programmes

SOPHOCLES will take advantage of the new observations being made from satellite sensors, ARGO sensors and focused processes studies that are being undertaken in both the ice and ocean communities as part of IPY. A co-ordinated Southern ocean observing system is being drawn up by SCAR and CLIVAR panels which we can take advantage of the processed data sets. ASPeCt has two sea ice cruises Sept-Nov 2007 in East Antarctic and Bellingshausen seas, and there have also been recent cruises outside IPY timeframe to Weddell Sea. The ocean community have two IPY projects CASO and SASSI the first covers the broader ocean observations, WOCE line and mooring arrays as well as ARGO deployments, the second is a continental shelf programme looking at details on shelf and shelf-slope processes in the ocean. The number of floats released by the international community in the Southern ocean has increased after a later start than in the other ocean basins to give us the most comprehensive coverage of the open ocean, and there are a few specialized floats operated by AWI under the Weddell Sea ice cover. Analyses of these data will give us detailed of the internal interannual variability of the southern ocean characteristics that we have only had limited coverage from satellite measurements. The satellite coverage of Southern ocean ice from microwave and altimeters and ocean temperature colour and SSH are expected to be continued in existing and planned satellite missions. SOPHOCLES will be relying on our observational colleagues and groups such as SOOS to turn these products into a form that can be compared with model output.

Processes

The purpose of the SOPHOCLES project is to focus on how well the models represent key processes and how we can improve the representation of those which have had less focus by the global community in the past. We will frame this section as a number of questions which we wish to answered.

Ocean

- How well do the models represent Southern ocean water masses, methods of formation/transformation, ocean mixing processes and dynamics of the major currents and thermohaline circulation?
- One of the key issues for the Southern ocean is the thermohaline circulation, is it driven realistically in the models, does it concur with the view derived from observations and inverse models built on those observations of an upper and lower limb. Are the densities on the shelf dense enough to form prototype Antarctic bottom water.
- Is the convection process localized to regions that observational evidence suggest do experience convection or is it to wide-spread due to incorrect parameterisations and too weak ocean stratification.
- Sensitivity of thermohaline circulation to FW fluxes from ice (both sea ice and glacial) and how this may change in future warmer scenarios.
- Water masses north of the sea ice edge how are they effected by sea ice processes and future warmer scenarios.
- How realistic are the ocean sub-grid scale processes in the model in particular in the region of ice-ocean interaction, forming of denser water masses, localized convection, downslope flows in canyons and eddy parameterisations?
- Do the atmospheric fluxes provide realistic conditions in the regions where SAMW and AAIW are formed and subducted?
- Does the water mass transformation of incoming circumpolar deep water, mirror the approach seen in the climate scale models or does extra resolution allow us to more closely match the descriptions observationalists have derived from inverse models.
- Are the processes driving the thermohaline circulation realistic in the models. How sensitive is the circulation to changes in the freshwater flux (precipitation, sea ice formation, glacial ice, ISW), that will occur in climate change simulations?

Sea-Ice

- How will sea ice change under global warming, and how will this impact global climate?
- How do changes in snow ice formation, timing of melt, and ice concentration affect the surface water stability?
- Why is the Arctic sea ice extent rapidly decreasing while the Antarctic sea ice is showing no significant trend. ?
- How well do current sea ice parameterisations represent the ice thickness distribution of the Antarctic sea ice pack, the rates of ice production particularly in polynyas and the increase in ice thickness due to snow ice conversion rates?
- Can the models correctly represent cases of local extreme ice thickness that have been seen to occur under particular forcing conditions, what is the horizontal resolution required to represent these heterogeneous features within the ice pack that can persist for several seasons and have an impact on the local sub-surface ocean conditions?
- Are the parameter settings used in the sea ice models suitable for the Antarctic ice pack, or have they

been too strongly optimized for Arctic conditions?

- Are the higher ice production rates within polynyas sufficient to generate the dense water masses on the shelves that are the prototypes for Antarctic bottom water?
- How important is the snow ice for maintaining ice thickness in a warming climate.

Ice shelves

- What are the role of fluxes from the glacial ice, iceberg melt to the freshwater balance in the Antarctic region, how do we include it in models and also include the sensitivity to warmer temperatures under climate change? How can we utilize the long term ocean sections to detect recent sources of melt and what additional tracers do we need in models (and observations) to distinguish between multiple freshwater sources.
- Can we use ocean/ice time series data from under the ice shelves (e.g. Amery) to constrain the under ice models and use the interannual variability of these records to define the climate sensitivity to small (< 1.0 ^{o}C) temperature change.
- Can we build better parameterisations of ice-shelf ocean exchange for inclusion in multi-century climate runs?
- How can we use regional ice shelf-ocean coupled to sea ice models to understand the full range of processes and interactions that our occurring in the present climate and the sensitivity of the system to climate change? We need to build on this work so that future higher resolution climate models can include the ice-shelf ocean processes directly even with models that are too coarse too accurately model the details of the circulation in the complex under ice shelf topography.

Expected output/outcomes

The aim of this project is to investigate how well current models represent key physical processes in the Southern Ocean and the interaction with the cryosphere. The outputs will be in the form of papers in the peer reviewed scientific literature. The project also has a role in model development, devising improved parameterisations that replace existing ones or include new processes. These new parameterisations will be tested in high resolution regional models of the cryosphere-ocean before being used in global scale ice-ocean climate models. The uptake of these parameterisations by the global coupled modelling community will probably depend on successful implementation by a few key groups who have an interest in the Southern ocean and improved outcomes and performance of those models. Again papers in the scientific literature and presentations at international conferences will alert the wider community to the outcomes of the SOPHOCLES project. Links to other modelling groups/panels will also inform the community of any new breakthroughs which we may be advocating need to be taken up more widely.

Some colleagues have raised the need to develop links to interactive ice sheets with changing ice shelves and the geometry of the ice shelf cavity, which we feel is beyond what we can achieve within SOPHOCLES, but once new parameterisations of ice shelf ocean interaction and global model resolution is sufficient to include ice shelf cavities have been successfully used by the climate community we should be ready in conjunction with ice sheet colleagues to make this next step.

UK Activities in ocean model development

Report for WGOMD August 2007

Helene Banks

Summary

Many ocean modelling activities in the UK are transitioning to use the NEMO ocean model; this includes operational ocean forecasting at the Met Office and National Centre for Ocean Forecasting, climate modelling at the Met Office Hadley Centre and as part of the NERC QUEST project, Arctic modelling at the Centre for Polar Observations and Modelling. New NERC funded strategic research programmes are also encouraging this transition and the UK has taken a lead in developing a global 1 degree configuration of NEMO (ORCA1) with enhanced resolution in the Tropics. The UK is also contributing to the development of NEMO for Shelf Seas applications building on experience with the widely-used POLCOMS model. ICOM is an adaptive mesh model which is being developed by Imperial College and Oxford University.

Introduction

Ocean modelling activities in the UK are a combination of both operational capability on all timescales and research activity. For many years the number of models used has been diverse with little transferable code between research and operational facilities. The UK strategy has now shifted towards a common shared code with transition to the NEMO (Nucleus for European Modelling of the Ocean) code taking place at the Met Office, NERC institutes and Universities. In parallel with this transition, an adaptive mesh capability is being developed by Imperial College and Oxford University.

Existing models

Work has continued to take place on existing models. The highlights are:

- OCCAM: NERC's high resolution global ocean modelling capability is being replaced by NEMO based models. However, analyses of key integrations of the OCCAM model with high frequency surface forcing will continue and will be used for early comparisons with the NEMO models. Important legacy datasets from the OCCAM project include a global simulation for 1985 to 2004 at 1/12^{o} degree resolution. A typical example of the ongoing analysis of this dataset involves the diagnosis of effective eddy diffusion from passive tracer fields stored at 5 day intervals.
- Coupled climate models: analysis of the HadGEM1 climate model has demonstrated the importance of resolving the Agulhas current. The Agulhas retroflection is not present in HadGEM1 and this leads to warming and salting in the Atlantic with an eventual impact on the thermohaline circulation.
- High resolution coupled models: the HiGEM (90km-1/3 degree) model has shown a much improved ENSO simulation compared to lower resolution models using

the same basic model. The enhanced zonal resolution near the equator seems to be important in signal propagation. Figure 1 shows the DJF precipitation anomalies associated with ENSO events from a model matrix comprising 135km and 90km atmosphere models, and 1-1/3 degree (varying, HadGEM) and 1/3 degree (uniform, HiGEM) ocean models.

- A NUGEM (60km-1/3 degree) model has also been developed, and shows promise of reducing/removing the warm SST bias associated with stratocumulus regions on the eastern boundaries of the Pacific and Atlantic Oceans.

NEMO transition

The Met Office and the NERC community (through Oceans2025) are committed to transitioning ocean modelling activities to use the NEMO (Nucleus for European Modelling of the Ocean) model. The status of the transition is:

- The Met Office operational forecast system FOAM is in the advanced stages of transitioning all operational models to NEMO. The first FOAM-NEMO configuration is now running operationally as a trial system. Work is underway to scope the feasibility of sharing model configurations with the French operational ocean modelling centre Mercator.
- The Met Office is contributing towards work to develop NEMO for shelf seas applications. Developments carried out by European partners are being tested at the Met Office in a tides-only configuration of the NW European Shelf (see figure 2), and a formal assessment of the tidal simulations against observations will be carried out by POL. Progress towards full baroclinic simulations is expected in the second half of the year.
- NOCS and ESSC are collaborating with DRAKKAR on high resolution modelling. Under the Oceans2025 programme NOCS will extend the DRAKKAR ORCA025 model ($1/4^{o}$) to include biogeochemistry and models of the carbon cycle. Higher resolution regional models of the North Atlantic will also be developed embedded in the global models using the two-way nesting options provided by the AGRIF features of NEMO. A global 1/12o NEMO model is planned during the latter part of the Oceans2025 programme.
- CPOM-UCL have developed a NEMO-CICE configuration for the Arctic Ocean which is forced by reanalysis and will be used for intercomparison with IPY observations.
- The Met Office, NOCS and ESSC have jointly developed the ORCA1 configuration of NEMO (nominal 1 degree ocean with enhanced resolution on the Equator).
- The Met Office Hadley Centre are building a new climate model (HadGEM3-AO) which will be based on the NEMO ocean model coupled to the UM atmosphere and CICE sea ice model.

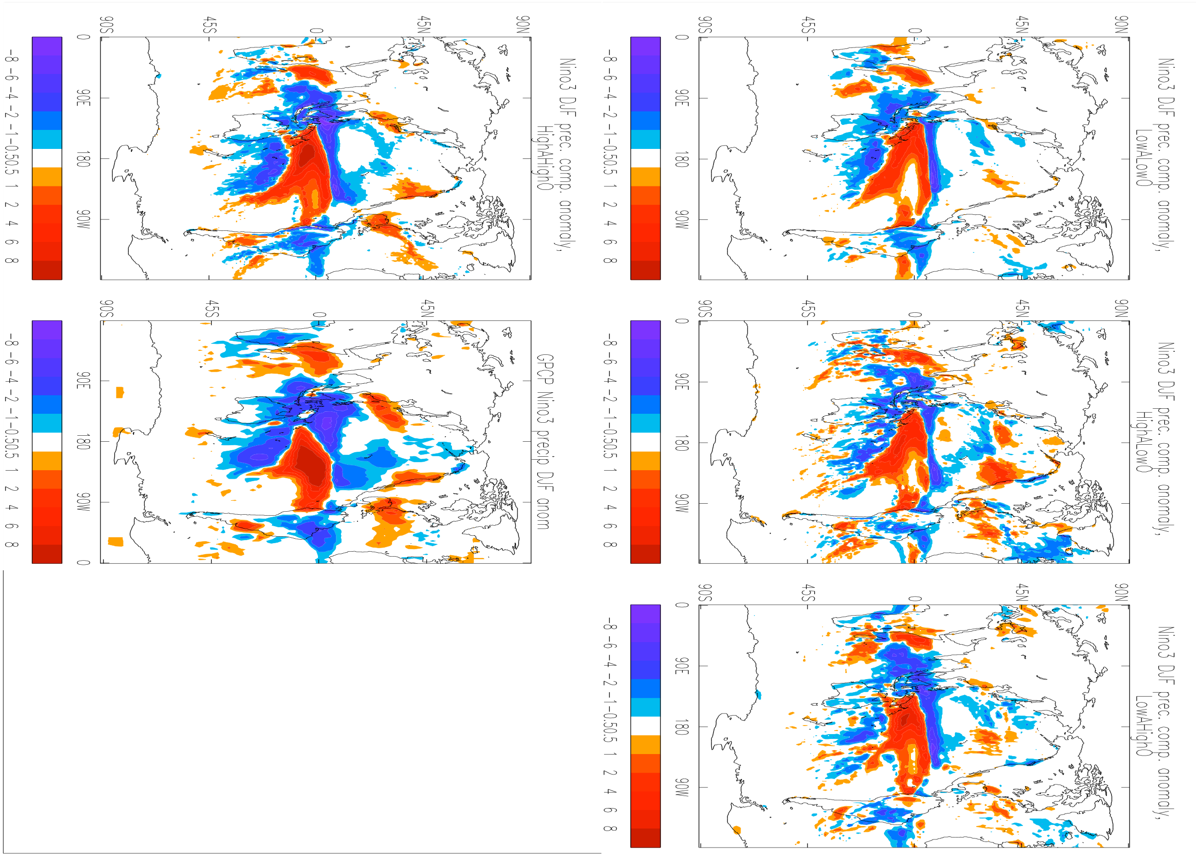

Figure 1: Precipitation anomalies with different ocean and atmosphere resolutions

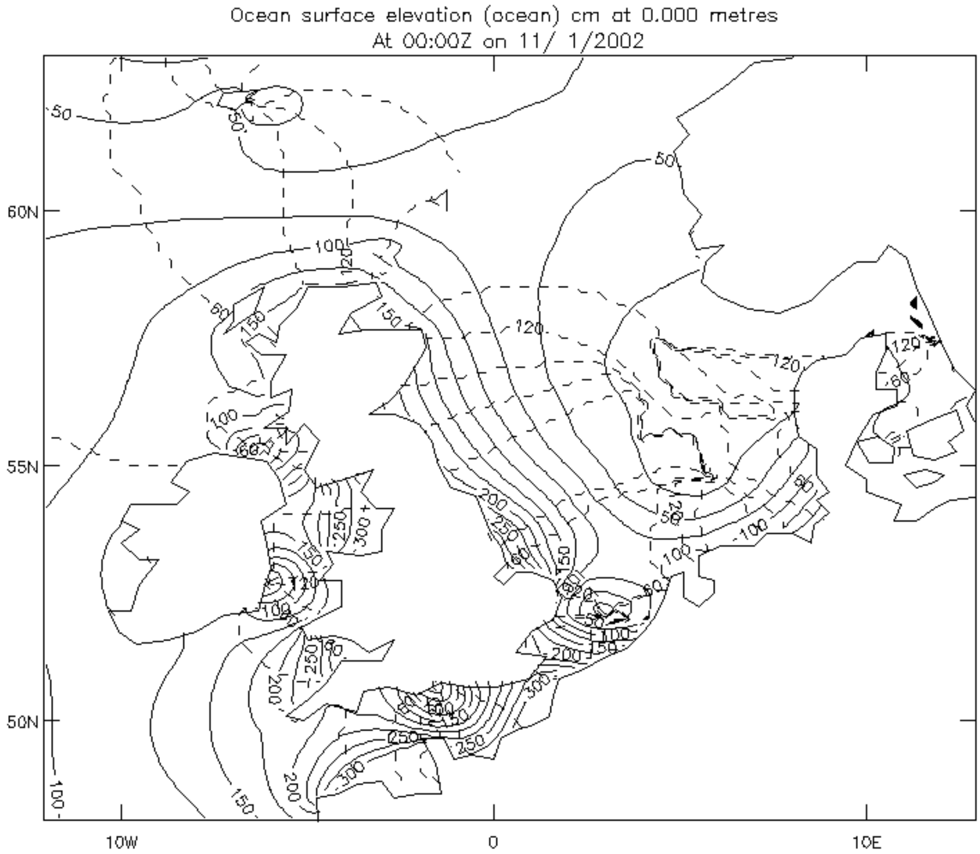

Figure 2: Cotidal plot showing amplitude (cm) and phase (deg) of tidal elevation for M2 semidiurnal tide in test configuration of NEMO for the NW European Shelf

Ocean model development in Germany
Claus Böning

MPIOM (http://www.mpimet.mpg.de/en/wissenschaft/modelle.html)
The current Max Planck Institute for Meteorology (MPI-M) ocean model MPIOM (Marsland et al., 2003; Jungclaus et al., 2006) is maintained and has been improved in terms of performance. The ocean biogeochemical sub-model HAMOCC5 (Wetzel et al., 2006) has been implemented and coupled atmosphere-ocean integrations with interactive carbon cycle are presently carried out in the framework of simulations of the last Millennium. A tidal module option has been included where the tides are driven by the complete lunisolar tidal potential without decomposition into Fourier components (Thomas et al., 2001). To accommodate for higher resolution global set-ups, a tri-polar grid version (similar to GFDL, OPA) has been developed. Aiming at a resolution of 0.45 degree for the standard configuration for the upcoming IPCC AR5 and a high-resolution (0.1 degree) version, the model is presently configured and parameterizations are being reviewed.
MPI-M has established a new research group on sea ice processes and modeling. One focus of the group is the development of a new multi-category, multi-layer sea ice model.

ICON (Icosahedral non-hydrostatic General Circulation Model) (http://icon.enes.org/)
ICON is a joint project between MPI-M's atmosphere and ocean departments and the German Weather Service (DWD) with the goal to develop a new coupled Atmosphere-Ocean General Circulation Model (GCM) that is capable to operate on a variety of space-time scales: from weather prediction to climate studies in regional and global domains.
We aim to implement a non-hydrostatic GCM for both atmosphere and ocean (with a hydrostatic version as an intermediate step). In order to exploit structural similarities between the equations for atmosphere and ocean we have started to develop a 'joint dynamical core' that is shared by the atmosphere and ocean components and contains the dynamics, while the physics and the different initial/boundary conditions are encoded in the individual model components.
Additional features of the ICON-GCM are:

- conservative local grid refinement (non-adaptive) that allows e.g. regional modeling in both atmosphere and ocean or local refinement along lateral boundaries in the ocean
- use of a common model grid for atmosphere and ocean that facilitates their coupling by avoiding spatial interpolation

The ICON model grid is an icosahedral geodesic grid, which is obtained by a regular Delaunay triangulation or by direct construction of the great circles of the sphere. The result is an almost uniform covering of the sphere. The variables are arranged in a C-type staggering (scalar variables at triangle centers, velocities at midpoints of triangle sides). The grid generator has been implemented, including the option for local refinement of triangles and a domain decomposition for parallelization.
As a preliminary ocean model version in 3D, the basic structure of the ocean model MPIOM with trapezoidal grid cells has been transformed to the triangular system without refinement. The actual code allows for a transition from hydrostatic to non-hydrostatic by

a switch. In both cases the speed of surface waves implies the solution of large systems of linear equations; for the non-hydrostatic case this system links together all scalar points in three dimensions.

References:

Thomas, M., J. Sündermann, and E. Maier-Reimer, 2001: Consideration of ocean tides in an OGCM and impacts on subseasonal to decadal polar motion excitation. *Geophys. Res. Lett*., 28, 12, 2457-2460.

Marsland, S.J., H. Haak, J.H. Jungclaus, M. Latif, and F. Roeske, 2003: The Max-Planck- Institute global ocean/sea-ice model with orthogonal curvilinear coordinates. *Ocean Modelling,* 5, 91-127.

Jungclaus, J.H., M. Botzet, H. Haak, N. Keenlyside, J.-J. Luo, M. Latif, J. Marotzke, U. Mikolajewicz, and E. Roeckner, 2006: Ocean circulation and tropical variability in the coupled model ECHAM5/MPI-OM. *Journal of Climate*, 19, 3952-3972.

Wetzel, P., E. Maier-Reimer, M. Botzet, J.H. Jungclaus, N. Keenlyside, and M. Latif, 2006: Effects of ocean biology on the penetrative radiation on a coupled climate model. *Journal of Climate,* 19, 3973-3987.

FEOM (Finite-Element Ocean circulation Model)

Many processes in the ocean depend on true representation of coastline and bottom topography which motivates current interest to models capable of working on unstructured grids. The Finite-Element Ocean circulation Model (FEOM) was developed at Alfred-Wegener-Institute for Polar and Marine Research (AWI) in Bremerhaven with recognition of the role played by true representation of geometry. It is designed to work on unstructured surface triangular grids and in addition to continuous ("smooth") representation of coastlines also allows for refinement in areas of interest thus providing nesting in a seamless way. We work with vertically aligned meshes to facilitate using the hydrostatic approximation.

FEOM in formulated in geopotential coordinates but supports generalized vertical grids including z, sigma and their combinations with variable numbers of levels. Partially and fully shaved cells with z coordinate vertical discretization are also supported. Two versions with prismatic or tetrahedral discretization are available.

FEOM solves the primitive equations based on pressure correction method (implicit linear free surface). It offers a choice of several advection schemes and supports typical parameterizations accepted in the oceanographic community i.e. Redi tensor, Gent-McWilliams, Smagorinsky, biharmonic viscosity, Pacanowsky-Philander mixed layer.

FEOM is coupled to a finite-element sea ice model that works on triangular surface meshes. For a technical description (pdf) please notify sergey.danilov@awi.de

Publications on FEOM:

Danilov, S., G. Kivman, J. Schroeter, 2004: A finite-element ocean model: principles and evaluation. *Ocean Modelling*, 6, 125-150.

Wang Q., S. Danilov, J. Schroeter, 2007: Comparison of overflow simulations on different vertical grids using the Finite Element Ocean circulation Model. *Ocean Modelling*, submitted.

Danilov, S., Q. Wang, J. Schroeter, 2007: Finite Element Ocean circulation Model based on prismatic elements. *Monthly Weather Review*, submitted.

SUMMARY OF NCAR OCEAN MODELING ACTIVITIES

Gokhan Danabasoglu (Representing NCAR)

Our major activities during the past year and a half include the following:

- Model development: We have recently switched to a POP2 base code that allows for both micro- and macro-tasking. This is expected to improve computational efficiency particularly at higher, i.e., eddy-resolving/permitting, resolutions. The incorporated developments in this new base code include

  - new horizontal (still nominal 1°) and vertical (60-level) grid,
  - Simmons et al. (2006) tidal mixing scheme,
  - Ferrari et al. (2007) near-surface eddy flux parameterization,
  - upper-ocean enhancement of eddy diffusivities,
  - reformulation of anisotropic horizontal viscosities,
  - passive tracer infrastructure and prognostic ecosystem model,
  - improved elliptic solver for better scalability,
  - revisiting tracer advection schemes,
  - additional diagnostics.

  This version of the ocean model is included in an intermediate version of the CCSM denoted as CCSM3.5. We plan to consider a few additions for the version to be used in the IPCC AR5.

- We continue to actively participate in the two ocean Climate Process Team (CPT) activities. The near-surface eddy flux parameterization and upper-ocean enhancement of eddy diffusivities listed above are direct results of our CPT collaborations on eddy-mixed layer interactions. As for the CPT on gravity current overflows, we have implemented an overflow parameterization for the Mediterranean overflow and documented its climate impacts in a recent paper in Ocean Modelling. Currently, we are extending this parameterization to the Denmark Strait and Faroe Bank Channel overflows.

- The CORE version 2 Normal Year and Inter-Annual data sets are being finalized.
- We have been continuing with further analysis of the ocean-only and coupled simulations of our existing CCSM3 simulations as well as the newer integrations with CCSM3.5. These include analysis of the overturning circulation and its multi-decadal variability in the present-day simulations, and water mass formation changes in the South Atlantic in the 21st Century integrations.
- We are collaborating with GFDL in our decadal predictability activities.
- We have been developing a global, $1/10^{\circ}$ eddy-permitting/resolving model to be used in climate simulations.

Ocean General Circulation Development in the Scandinavian Countries (Denmark, Norway, Sweden), 2007

by
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Nansen Center (NERSC) and Bjerknes Centre (BCCR), Bergen, Norway

with input from

Mats Bentsen (mats.bentsen@nersc.no; NERSC/BCCR, Norway)
Ralf Doescher (Ralf.Doescher@smhi.se; SMHI, Sweden)
Paul W Budgell (paul.budgell@imr.no; Institute of Marine Research, Bergen and BCCR, Norway)
Lars Petter Rød (larspetter.roed@met.no; Meteorological Institute, Oslo, Norway)

1. DENMARK

1.1 Danish Meteorological Institute, DMI

No input yet – vacation time...

2. SWEDEN

2.1 Swedish Meteorological and Hydrological Institute, SMHI

At the Swedish Meteorological and Hydrological Institute (SMHI), ocean modelling is done for climate studies, physical and biogeochemical process studies and for operational forecasts. Modelling projects are focusing on the Arctic, the Baltic Sea and global studies.

Model systems in use are the Rossby Centre regional ocean model RCO[1] (derived from OCCAM), the global coupled model CCSM3 including ocean component and the operational ocean model HIROMB (High Resolution Operational Model for the Baltic Sea[2]). During fall 2007, the ocean model NEMO (OPA) will be adopted for a global domain, later also in the regional domains.

Current and near future modeling activities are:

- Coupled ocean-ice-atmosphere runs for a regional Baltic Sea domain in 6 nautical miles (nm) and 2 nm resolution, using RCO ocean, coupled by OASIS4.
- Coupled physical-biogeochemical runs for the Baltic Sea using RCO-SCOBI (2 and 6 nm resolution) for 100-year long simulations (hindcasts and scenarios).

[1] http://www.smhi.se/sgn0106/if/rc/rco.htm
[2] http://www.smhi.se/oceanografi/oce_info_data/models/hiromb.htm

- Regional Arctic coupled ocean-ice-atmosphere process studies, predictability studies and climate scenarios, using RCO ocean model in 0.5 and 0.25 degrees resolution.
- Regional Arctic ocean-ice process studies on interdecadal variability and biogeochemical processes, using RCO ocean model in 0.5 and 0.25 degrees (or better), for 100-year long simulations (with new sea-ice module).
- Global coupled ocean-ice atmosphere climate runs, using NEMO (OPA)
- High resolution Baltic Sea runs using RCO-SCOBI with at least 1 nm resolution (25-year long simulations)

A list of recent publications based on SMHIs OGCM-system(s):

Döös, K., Meier, H. E. M. and Döscher, R. 2004. The Baltic Haline Conveyor Belt or The Overturning Circulation and Mixing in the Baltic. Ambio 33:4-5, 257-260.

Döscher, R. and Meier, H. E. M. 2004. Simulated Sea Surface Temperature and Heat Fluxes in Different Climates of the Baltic Sea. Ambio 33:4-5, 242-248.

Kjellström, E., Döscher, R. and Meier, H. E. M. 2005. Atmospheric response to different sea surface temperatures in the Baltic Sea: Coupled versus uncoupled regional climate model experiments. Nordic Hydrology 36:4-5, 397-409.

Meier, H. E. M. 2005. Modeling the age of Baltic Seawater masses: Quantification and steady state sensitivity experiments. J. Geophys. Res. 110, C02006, doi:10.1029/2004JC002607.

Meier, H. E. M. 2005. The doubly stratified regime: turbulence closures for an OGCM of the Baltic Sea. In: H. Z. Baumert, J. Simpson, and J. Sündermann (eds.), Marine Turbulence: Theories, Observations, and Models. Results of the CARTUM Project, chapter 47, Cambridge University Press, Cambridge, 376-382.

Meier, H. E. M. 2006. Baltic Sea climate in the late twenty-first century: a dynamical donwscaling approach using two global models and two emission scenarios. Clim. Dyn. 27, 39-68, doi:10.1007/s00382-006-0124-x.

Meier, H. E. M., Broman, B. and Kjellström, E. 2004. Simulated sea level in past and future climates of the Baltic Sea. Clim. Res. 27, 59-75.

Meier, H. E. M., Broman, B., Kallio, H. and Kjellström, E. 2006. Projections of future surface winds, sea levels, and wind waves in the late 21st Century and their application for impact studies of flood prone areas in the Baltic Sea region. In: Schmidt-Thomé, P. (ed): Sea level change affecting the spatial development of the Baltic Sea region, Geological Survey of Finland, Special Paper 41, 23-43.

Meier, H. E. M., Döscher, R. and Halkka, A. 2004. Simulated Distributions of Baltic Sea-ice in Warming Climate and Consequences for the Winter Habitat of the Baltic Ringed Seal. Ambio 33:4-5, 249-256.

Meier, H. E. M., Döscher, R., Broman, B. and Piechura, J. 2004. The major Baltic inflow in January 2003 and preconditioning by smaller inflows in summer/autumn 2002: a model study. Oceanologia 46, 557-579.

Meier, H. E. M., Kjellström, E. and Graham L. P. 2006. Estimating uncertainties of projected Baltic Sea salinity in the late 21st century, Geophys. Res. Lett. 33, L15705, doi:10.1029/2006GL026488.

Meier, H.E.M. 2007. Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea. Estuarine, Coastal and Shelf Science, Vol. 74/4, 717-734.

Räisänen, J., Hansson, U., Ullerstig, A., Döscher, R., Graham, L. P., Jones, C., Meier, H. E. M., Samuelsson, P. and Willén, U. 2004. European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. Clim. Dyn. 22, 13-31.

3. NORWAY

The main groups working with OGCM development in Norway are located in Bergen and in Oslo, with a minor activity in Tromsø.

The following OGCMs are in use in Norway for climate studies:

1) HYCOM/MICOM (both in Bergen and in Oslo)
2) MITgcm (in Bergen and Tromsø)
3) ROMS (in Bergen)

3.1 Bergen / Bjerknes Centre for Climate Research (BCCR) (Institute for Marine Research IMR, Nansen Environmental and Remote Sensing Center NERSC, and University of Bergen UoB)

All climate related research in Bergen, students, PostDocs and scientists included, is organized under the Bjerknes Centre for Climate Research (http://www.bjerknes.uib.no). In 2007, about 30 person years are devoted to integrating, analysing and improving the OGCMs in use in Bergen.

The activity with HYCOM/MICOM is largest, representing about 80% of the total effort. The Nansen Center version of MICOM (Bentsen et al., 2004; Drange et al. 2005) is used as the ocean part of the global, fully coupled Bergen Climate Model (e.g., Furevik et al., 2002, Sorteberg et al., 2005), participating in the IPCC 4AR.

The following classes of studies are carried out:

1) Global and basin spatial scale, interannual to centennial time scale climate studies (NERSC version of MICOM and ROMS, both fully coupled to dynamic/thermodynamic sea ice modules)
2) Global and basin spatial scale, interannual to centennial time scale climate studies on ecosystem and carbon cycle (HYCOM/NERSC version of MICOM)
3) Process studies (all model systems)
4) Global climate modelling with the *Bergen Climate Model* (participating in IPCC 4AR) (NERSC version of MICOM)
5) Data assimilation (HYCOM)

3.1.1. Status Climate OGCM at Nansen Center/Bjerknes Centre (Mats Bentsen/Helge Drange)

All of the activities are based on the Nansen Center version of MICOM. Two global versions and one regional (Atlantic-Arctic) version are available:

(i) Global model with grid focus in the Atlantic Ocean (35 isop layers; 80 and 40 km horiz resolution in the focus region; grid poles over Europe and N America).

(ii) Regional Atlantic-Nordic Seas version embedded into model (i) with about 20 km horizontal resolution in the northern North Atlantic, otherwise identical to the parent model.

(iii) Global version with poles over Siberia and Antarctica (35 isop layers; 1.5 cosφ (Mercator) horizontal resolution), and with enhanced meridional resolution along equator.

Model version (iii) forms the ocean component of the global coupled Bergen Climate Model (BCM). Major achievement with version (iii) has been completion of the IPCC 4AR runs without heat or fresh water flux adjustments.

The Nansen Center version of MICOM deviates from the basic MICOM code by the following features:

- Layer conservation
- Advection of *T* and *S*, including restoration towards reference density
- Convection rewritten
- Diapycnal mixing reformulated
- Cabbeling included (caused by diffusion)
- Entrainment and detrainment modified for polar conditions (where $\delta\rho$ is governed by δS, not δT as at lower latitudes)
- Solar irradiance + polar brine plumes below mixed layer (treated as diapyc fluxes)
- Proper treatment of layer diff near topography (avoiding creeping isopycnals)
- Fix to improve numerical stability (velocity limiting in barotrop and barocline solver)
- Viscosity fix (large viscosity to reduce noise & long time step)
- Virtual *S*-flux for ocean-only experiments (local reference *S*; global fresh water conservation by globally adjusted SSS)
- Rewritten thermodynamics (single-layer ice and snow, conservation of heat and fresh water, similar code for coupling and ocean only)
- Updated dynamic sea ice (MPDATA advection scheme)
- Continental runoff routed by the TRIP data base
- Zero-order adjustment of NCEP forcing fields (conservation, solar irradiance)
- Online interpolation of NCEP forcing fields to actual model grid

The model system has been applied to, in particular, addressing fluctuations in the marine climate of the northern North Atlantic, the Nordic Seas and the Arctic Ocean.

Recent (post 2005) publications

Bethke, I., T. Furevik, and H. Drange (2006), Towards a more saline North Atlantic and a fresher Arctic under global warming, *Geophys. Res. Lett.*, 33, L21712 [file]

Collins, M., M. Botzet, A. Carril, H. Drange, A. Jouzeau, M. Latif, O. H. Otterå, H. Pohlmann, A. Sorteberg, R. Sutton, L. Terray (2006): Interannual to decadal climate predictability: A multi-perfect-model-ensemble study. *J. Climate*, 19, 1195-1203, doi:10.1175/JCLI3654.1 [file]

Deshayes, J., C. Frankignoul, and H. Drange (2007), Formation and export of deep water in the Labrador and Irminger Seas in a GCM, *Deep Sea Research 2*, in press [file]

Drange, H., R. Gerdes, Y. Gao, M. Karcher, F. Kauker, and M. Bentsen (2005), Ocean general circulation modelling of the Nordic Seas, in *The Nordic Seas: An Integrated Perspective*, (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 199-220 [file] [book]

Drange, H., T. Dokken, T. Furevik, R. Gerdes, W. Berger, A. Nesje, A. A. Orvik, Ø. Skagseth, I. Skjelvan, and S. Østerhus (2005), The Nordic Seas: An introduction, in *The Nordic Seas: An Integrated Perspective* (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 1-10 [file] [book]

Eldevik, T. , F. Straneo, A.B. Sandø, and T. Furevik, 2005: Pathways and export of Greenland Sea Water. *The Nordic Seas: An integrated perspective*, H. Drange, T.M. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds., Geophysical Monograph Series, AGU, 89-103

Gao Y., Drange H., Bentsen M., Johannessen O.M. (2005), Tracer-derived transient time of the eastern waters in the Nordic Seas, *Tellus*, 57B, 332-340 [file]

Hátún, H., A. B. Sandø, H. Drange, B. Hansen, and H. Valdimarsson (2005), Influence of the Atlantic Subpolar Gyre on the Thermohaline Circulation, *Science*, 309, 1841-1844 [article] [info]
Hátún, H., Sandø, A. B., Drange, H. and Bentsen, M. (2005), Seasonal to decadal temperature variations in the Faroe-Shetland inflow waters, in *The Nordic Seas: An Integrated Perspective*, (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 239-250 [file] [book]
Kuzmina, S. I., L. Bengtsson, O. M. Johannessen, H. Drange, L. P. Bobylev and M. W. Miles (2005): The North Atlantic Oscillation and greenhouse-gas forcing, *Geophys. Res. Lett.*, 32, L04703, doi:10.1029/2004GL021064 [file]
Mauritzen, C., Hjøllo, S. and Sandø, A. B. (2006). Passive tracers and active dynamics - a model study of hydrography and circulation in the northern North Atlantic, *J. Geoph. Res.*, 111 , C08014, doi:10.1029/2005JC003252 [article]
Orre, S., Y. Gao, H. Drange, and E. Deleersnijder (2006), Transport and time scales associated with idealized trasers released in the North-East Atlantic, *Eust., Coastal Shelf Sci.*, in revision
Orre, S., Y. Gao, H. Drange, and J. E. Ø. Nilsen (2006), A reassessment of the dispersion of Technetium-99 in the North Sea and the Norwegian Sea, *J. Mar. Sys.*, doi:10.1016/j.marsys.2006.10.009 [file]
Risebrobakken, B., Dokken T., Otterå O. H., Jansen E., Y. Gao, H. Drange (2006), Inception of the northern European ice sheet due to contrasting ocean and insolation forcing, *Quaternary Research*, 667, 128-135, doi:10.1016/j.yqres.2006.07.007 [file]
Siegismund, F., J. Johannessen, H. Drange, K. A. Mork, A. Korablev (2007), Steric height variability in the Nordic Seas *J. Geophys. Res.*, accepted [file]
Sorteberg, A., T. Furevik, H. Drange, and N. G. Kvamstø (2005), Effects of simulated natural variability on Arctic temperature projections, *Geophys. Res. Lett.*, 32, L18708, doi:10.1029/2005GL023404. [file]
Su, J., H.-J. Wang, H. Yang, H. Drange, Y. Gao, and M. Bentsen (2007), Role of the atmospheric and oceanic circulation in the tropical Pacific SST changes, *J. Clim.*, accepted
Vikebø F, Sundby S, Ådlandsvik B, Otterå OH (2007) Impacts of a reduced THC on transport and growth of Arcto-Norwegian cod, *Fisheries Oceanography*, 16 , No. 3, 216-228
Zhou, T. J., and Drange H. (2005), Climate Impacts of the Decadal and Interannual Variability of the Atlantic Thermohaline Circulation in Bergen Climate Model, *Chinese J. Atm. Sci.*, 29, 167-177 (Chinese journal with English abstract) [file]

3.1.2 Development of a new layered OGCM at NERSC/BCCR (Mats Bentsen)

Goals: Should perform well with coarse and fine horizontal resolution; should be suited as a component of an Earth System Model (many tracers; amplitude, shape, phase, conservation, capability and efficiency are here important properties).

Status: The development concentrates on the use of isopycnic vertical coordinate, with possible extension to a hybrid coordinate. As such it represents an extension to the existing HYCOM/MICOM class of OGCMs. Likely, the R-grid will be used for the horizontal staggering. A generalized forward-backward algorithm will most likely be used for time stepping. Incremental remapping for the transport algorithm will likely be used. The latter is a method suited for B-grid models, but it has been adapted to be used with C-grid. The R-grid, time stepping and remapping are all being tested in idealized setup of the model, and some with a realistic (global) model configuration.

Test versions of the new OGCM are being tested (2007). The OGCM is also coupled to

the ocean biogeochemistry model HAMOCC5.1 from the Max-Plank Institute for Meteorology in Hamburg, leading to a new isopycnic ocean carbon cycle model.

Specific features:

- Horizontal grid: Structured (finite difference)
- Vertical grid: Layer-based (finite difference)
- Possibly reversibly staggered horizontal grid (R-grid) by McGregor (2005)
- Possibly extended version of Shchepetkin and McWilliams (2005) generalized forward-backward algorithm
- Transport discretization by incremental remapping (Dukowicz and Baumgardner, 2000)

3.1.3 Status ROMS Model for the North Atlantic and Arctic Oceans (Paul W Budgell)

The main motivation for this activity is to provide consistent boundary conditions for regional modelling of the Norwegian waters for, in particular, ecosystem studies with a high-resolution version of the same model.

Performed integrations with ROMS v2.1: North Atlantic domain, 20-30 km horizontal resolution; regional model covering the Barents Sea with 9 km horizontal resolution Ongoing/planned simulations with ROMS v3.0: Global with grid focus in the Atlantic (20 km in grid focus region; European shelf model (from Spain to the Kara Sea/Russia) with 4 km horizontal resolution.

The ice dynamics are based upon the elastic-viscous-plastic (EVP) rheology of Hunke and Dukowicz (1997), Hunke (1991) and Hunke and Dukowicz (1992). Under low deformation (rigid behaviour), the singularity is regularized by elastic waves. The response is very similar to viscous-plastic models in typical Arctic pack ice conditions. The numerical behaviour improved significantly by applying linearization of the viscosities at every EVP time step. The EVP model parallelizes very efficiently under both MPI and OpenMP.

The ice thermodynamics are based upon those of Mellor and Kantha (1989) and Häkkinen and Mellor (1992). Main features include: Three-level, single layer ice; single snow layer; Molecular sublayer under ice; Prandtl-type ice-ocean boundary layer; Surface melt ponds; Forcing by short and long-wave radiation, sensible and latent heat flux; NCEP fluxes, corrected for model surface temperature and ice concentration, used as forcing.

Summary: The model captures seasonal variability in the Barents Sea: Good agreement with observed ice distribution; Good agreement with temperature, salinity ~ 0.1 too low; Brine rejection from ice formation produces realistic water masses; ROMS captures significant portion of mesoscale variability even with 9 km resolution.

Recent publications:

Bergamasco, A., W.P. Budgell, S. Carniel and M. Sclavo, 2005, Cryosphere-hydrosphere interactions: Numerical modeling using the Regional Ocean Modeling System (ROMS) at different scales, Il Nuovo Cimento, 28C(2): 173-181. DOI 10.1393/ncc/i2005-10181-6.

Budgell, W.P., 2005, Numerical simulation of ice-ocean variability in the Barents Sea region: Towards dynamical downscaling, Ocean Dynamics, DOI 0.1007/s10236-005-0008-3.

Lien, V., W.P. Budgell, B. Ådlandsvik and E. Svendsen, 2005, Volume transports and heat fluxes in the Nordic Seas. Results from ROMS (Regional Ocean Modelling System). Draft manuscript.

Svendsen, E., M.D. Skogen, W.P. Budgell, G. Huse, J.E. Stiansen, B. Ådlandsvik, F. Vikebø, L. Asplin and S. Sundby, 2005. An ecosystem modeling approach to predicting cod recruitment, submitted to Progress in Oceanography.

3.2 Status Oslo Regional Climate Model (ORCM) (Lars Petter Rød/Jens Debernard)

In Oslo, 4-5 persons work on ocean climate modelling.

ORCM covers the northern North Atlantic and the Arctic Ocean. The model consists of the atmosphere model HIRHAM (dynamics HIRLAM v2 and physics ECHAM4), MICOM (0.25° horizontal resolution and 27 density layers), and a sea ice module (EVP dynamics, one ice layer with prognostic internal energy + insulating snow cover, 0.25° horizontal resolution).
The ice-ocean model is driven at the lateral boundaries by a basin-wide Atlantic version of the same model. The Atlantic ice-ocean model can be driven at the lateral boundaries by input from any ocean-atmosphere model; presently it is driven with climatology and re-analyses (WOA2001 and ERA40). The atmosphere model is driven directly at the lateral boundaries; presently with ERA40.

Preliminary simulations from 1990-1999 have been completed. An intercomparison of these results from similar simulations with coupled regional climate models from Sweden (SMHI-RC) and Germany (AWI-Potsdam) is underway. An ERA40 downscaling for the time period 1970-2000 is in production. In 2006, coupled dynamical downscaling of results from the BCM is scheduled.

Recent publications

Debernard, J., et al., 2003: Improvements in the sea-ice module of the regional coupled atmosphere-ice-ocean model and the strategy and method for the coupling of the three spheres. *In: RegClim Tech. Rep. No. 7*, Eds. T. Iversen and M. Lystad, 59-70. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

Røed, L. P. And J. Debernard, 2004: Description of an integrated flux and sea-ice model suitable for coupling to an ocean and atmosphere model. *met.no Report No. 4*. ISSN 1503-8025.

Røed, L. P., and J. Debernard, 2005: Simulations with a North Atlantic coupled ice-ocean model. *In: RegClim Tech. Rep. No. 8*, Eds. T. Iversen and M. Lystad, 69-81. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

Debernard, J., and M. Ø. Køltzow, 2005: Technical documentation of Oslo Regional Climate Model, Version 1.0, *In: RegClim Tech. Rep. No. 8*, Eds. T. Iversen and M. Lystad, 51-68. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

Røed, L. P., and J. Debernard, 2005: Documentation of the method for nesting of MICOM variables into met.no's MICOM version (in preparation).

Ocean Modelling Activities in Canada

Report to the CLIVAR Working Group for Ocean Model Development

Submitted by Richard Greatbatch, July 2007

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1. Canadian Climate Centre for Modelling and Analysis, Victoria, BC (Bill Merryfield and Ken Denman)

The CCCMA ocean model is a primitive equation, *z*-coordinate global model, currently with 1.41° lon × 0.94° lat horizontal resolution, and having 33 or 40 levels with 15 m and 10 m vertical resolution in the upper ocean respectively. Physical parameterizations include the anisotropic viscosity parameterization of Large et al. (JPO 2001), the tidal mixing parameterization of Simmons et al. (OM 2004), an updated version of the KPP vertical mixing parameterization (Danabasoglu et al. J Clim 2006), variable-coefficient isoneutral mixing after Gnanadesikan et al. (JClim 2006), and the McDougall et al. (JAOT 2003) equation of state. Enhancements of horizontal resolution by factors of 3/2 and 2 are planned in the near future for coupled modeling use.

A coarser version of the model (1.87° lon × 1.87° lat × L29) supports a global ocean carbon model with inorganic carbon chemistry that follows the OCMIP2 protocols. The biological pump is represented in a 4-component ecosystem model with Nutrients, Phytoplankon, Zooplankton and organics Detritus (NPZD) state variables. The model includes new parameterizations for iron fertilization, calcification, and N2-fixation. It has been tested in stand-alone mode in preindustrial, historical and fertilization simulations. It is now embedded in the CCCMA fully-coupled carbon climate model: we have performed a stable 2000-year preindustrial simulation, and are currently running 1850 to 2100 climate change simulations.

2. Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, BC.

(i) Mike Foreman:

1) Circulation modelling off the entrance to Juan de Fuca Strait using ROMS for a harmful algal bloom project;
2) circulation modelling in the Broughton Archipelago using finite element and finite volume techniques for aquaculture issues;
3) finite element, data assimilating, tidal modeling around Vancouver Island and in the Bering Sea;
4) sea surface topography modelling in the Northeast Pacific for the GEOIDE Network;
5) collaborating with RA Tsuyoshi Wakamatsu in a circulation model for the North Pacific that assimilates Argo and satellite atlimetry.

(ii) Greg Holloway: Arctic regional ocean-ice modeling and is a participant in Arctic ocean Model Intercomparison Project (AOMIP).

(iii) Rick Thomson and Scott Tinis:

Tidal forecast model for Southern British Columbia: This model runs daily and provides users with images of tidal currents over a variety of locations in and around the Strait of Georgia and Juan de Fuca Strait. Although it serves as a defacto placeholder for future model incarnations that will include wind, river runoff and near realtime temperature and salinity, and it appears to be popular with stakeholders (consistently on the top ten list for hits on the DFO Pacific Science webserver).

Northeast Pacific model: This is a 1/8 degree coupled model (one-way coupling using input from the US Navy COAMPS atmospheric model) currently being developed for DND's Pacific fleet.

Storm Surge Forecast: A series of nested models is being developed (and is currently operational for BC government stakeholders) to provide a high-resolution (800 m) forecast for storm surge out to 48 hours for Victoria and the Lower Mainland of BC. The model is also used for extreme event hindcasts and future climate change impact research currently underway.

3. **The University of Victoria (Andrew Weaver and Michael Eby):**

Our group has focused a lot of attention recently on the carbon cycle. We have developed (along with Andreas Schmittner at OSU) a comprehensive carbon cycle-climate model. The ocean component includes an NPZD ocean biology model and the required additional ocean chemistry. An ocean sediment model has also just been added. These models coupled to the rest of the UVic Earth System Climate Model allow long term climate simulations with carbon as a completely prognostic variable. Many experiments have already been carried out including the assessment of the long term fate of anthropogenic CO_2, the effect of changing Southern Ocean winds on carbon uptake and the carbon cycle response to a collapse of the Atlantic overturning circulation.

We have also carried out many high resolution experiments looking at the sensitivity to resolution of the ocean response to climate warming and fresh water perturbations. This involves running coupled global climate models from 3.6 down to 0.2 degrees of resolution. Long runs of the coupled model have also been carried out to look at ocean variability over the past 120 thousand years. Various acceleration schemes for this type of long run have also been explored. Finally we have looked at "tidal mixing" schemes (a parametrization vertical mixing) and how sensitive the model is to expected changes in tidal energy in the LGM climate.

4. **The University of British Columbia (William Hsieh):**

My group has been developing machine learning methods (especially neural network methods) for ocean and climate modelling: (1) to improve the parametrization in dynamic or hybrid coupled models of the tropical Pacific (Li et al. 2005; Ye and Hsieh, 2006), (2) to extract nonlinear modes of oscillation using nonlinear principal component analysis, nonlinear canonical correlation analysis and nonlinear projection (Hsieh, 2004; Rattan et al. 2005; Hsieh 2007; Wu et al. 2007), (3) to forecast tropical Pacific sea surface temperatures (Wu et al. 2006).

5. **The University of Northern British Columbia (Youmin Tang):**

The group of climate prediction and data assimilation in UNBC has been working on oceanic data assimilation and the development of coupled models for ENSO prediction. Three ENSO dynamical prediction models have been developed/applied to investigate ENSO predictability of past 120 years from 1881-2000. These models include Lamont LDEO5 ENSO prediction model, OPA9.1 OGCM coupled with a linear statistical atmospheric model and an intermediate oceanic dynamical model coupled with a nonlinear statistical atmospheric model. A long-term historic sea surface temperature (SST) dataset has been assimilated into individual oceanic models to initialize ENSO hindcasts from 1881-2000, using Ensemble Kalman filter (EnKF) and optimal interpolation (OI) algorithms respectively.

6. **The University of Alberta (Paul Myers):**

There are 4 individuals (Andy Bush, Paul Myers, Bruce Sutherland and Gordon Swaters) involved in ocean modelling activities to some degree at The University of Alberta. These individuals are divided between the Earth and Atmospheric Sciences and Mathematics and Statistics Departments. Models run range from simplified 2-layer reduced gravity models to coupled 3-D general circulation models of the ocean/atmosphere system (MOM2 with MM5) and the ocean/sea-ice system (NEMO).

Scientific questions being investigated with these models include: Internal gravity wave (IGW) propagation, stability and breaking, IGW generation from turbulence and collapsed mixed regions, ocean mixing and restratification, gravity currents and downslope flows, changes in ENSO through time, glacial meltwater pulses and rapid climate change, Labrador Sea convection through time, impact of freshwater on Labrador Sea convection, role of Irminger Water in the sub-polar gyre, representation of the boundary currents in the sub-polar gyre, impact of exchange between the Arctic Ocean and the North Atlantic, as well as a new project to examine the impact of sea-ice data assimilation in the NEMO coupled model.

7. **The University of Waterloo (Kevin Lamb, Marek Stastna and Francis Poulin):**

Two- and three-dimensional models are being used to study small scale processes in the ocean, including parametric subharmonic instability of oscillating sheared currents (Poulin), many aspects of the generation, evolution and dissipation of internal solitary waves (Lamb, Stastna) and nonlinear interaction among tidally generated internal waves in the deep ocean. The numerical models used include the two-dimensional internal gravity wave model developed by Lamb, the MITgcm model for 3D internal wave generation studies, and a shallow-water barotropic model developed by Poulin. The POM model has also been used in the recent past. Currently a new spectral model is under development to model three-dimensional, viscous stratified flow over topography.

8. Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, NS.

(i) Charles Hannah:

At BIO a major initiative is the development of a shelf oriented version of the OPA-NEMO model for integration into the Canada-Newfoundland Operational Oceanography Forecasting System (C-NOOFS) and for other applications. Development continues on the Gulf of St. Lawrence biophysical modeling system, the ice-ocean forecasting system for the east coast, air-sea interactions, wave forecasts and an improved representation of the near-surface dynamics. In the near-shore the focus is on evaluating the unstructured mesh model FVCOM for use as a standard modeling tool.

(ii) Dan Wright:

The following provides a brief overview of Basin-to-Global Scale Modelling undertaken jointly by the Bedford Institute of Oceanography and the Center for Marine Environmental Prediction at Dalhousie University. A major aspect of our joint work is focused on the development of a global eddy-permitting ocean model suitable for use as a component of a global, coupled, data assimilative ocean-atmosphere-sea ice model to be used in weather prediction (oceanic and atmospheric) over time scales of hours to months. Much of the development work is being done in a North-Atlantic sub-domain with 46 levels in the vertical and nominally 1/4 degree horizontal resolution. The model code presently used is NEMO, version 2 and use of the ORCA025 grid results in finer resolution at high latitides, notably in the Canadian Archipelago.Imbedded finer resolutions subdomains will be used where higher resolution is desirable. Parallel developments with reduced emphasis on data assimilation are ongoing with one degree models of both the global ocean and the Arctic basin using the same numerical code. These one degree modelling initiatives are aimed more at hindcasting ocean climate variability and the interpretation of major observed changes.

(iii) Frederic Dupont:

(i) Ice-ocean modelling of the Canadian Archipelago using a finite volume unstructured grid model (FVCOM);
(ii) ice-ocean-biology Pan-Arctic modelling using MOM-2+Neptune (Holloway and Sou).

9. **Dalhousie University (Richard Greatbatch and Jinyu Sheng):**

Studies using the CANDIE Ocean Model with applications to the Northwest Atlantic Ocean (eddy-induced mixing and dynamics, wind work), the Inter-American Seas (transport variability, eddy dynamics, coral reef ecosystems), the Scotian Shelf (in particular Lunenburg Bay and the Bras d"Or Lakes as part of multidisciplinary projects) and Lake Huron. Extensive use is made of the semi-prognostic adjustment technique, not only to prevent model drift but also to link models in a highly successful nested modeling system. The method is both powerful and computationally efficient.

Studies using the FLAME model developed in Kiel, Germany applied to transient tracer simulation, near-inertial energy input to the ocean, the role of eddies in the ocean circulation.

10. **Memorial University of Newfoundland (Entcho Demirov):**

An ocean general circulation is developed in Memorial University for studies of the North Atlantic long term variability. The code is based on the ORCA-NEMO coupled sea-ice model, which is implemented for the North Atlantic region from 30S to 80N. The model is used in the following research projects:

1) Global Ocean and Atmosphere Prediction and Predictability (GOAPP) funded by CFCAS. A data assimilation scheme based on the SEEK filter is under development for the North Atlantic Model. This scheme will be used in assimilation of both hydrographic and sea-ice data.

(2) CFCAS funded project: "The response of the Labrador Sea environment to global climate changes: modeling, diagnose and predictability". The major idea of this project is to use the North Atlantic model and data assimilation scheme for 50 years (from the 1950 to 2000) re-analysis (hindcast) of the North Atlantic using all available data (temperature, salinity, sea-ice and sea surface height).

(3) NSERC funded project: "High resolution modeling of the Labrador Sea: Variability, processes of deep convection and interaction with the global ocean". The major objective of this model study is the interaction between the Labrador Sea and North Atlantic Ocean based on the 50 years reanalysis.

11. **Northwest Atlantic Fisheries Centre, Department of Fisheries and Oceans, St. John's Newfoundland (Fraser Davidson):**

Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS):

The development here focusses on operational oceanographic applications with particular emphasis on downscaling from Global Ocean Forecasting systems. While the global systems use rigid lid, the Canada-Newfoundland ocean forecasting system makes use of the free-surface version of NEMO. The regional system is ran in a test mode for operations at 1/4 degree resolution (www.c-noofs.gc.ca) with 2 way nested subgrid at 1/12 of a degree resolution for Atlantic Canada in the implementation process. The model domain is a subset of the Global Orca grid and allows for maximum resolution in the Canadian Arctic Achipelago due to the tri polar grid arrangement. C-NOOFS is a component of the GODAE downscaling effort as well as the European MERSEA project in operational oceanography.

Summary of GFDL ocean climate modeling activities: 2005-2007
Stephen Griffies (representing GFDL)

Major activities occupying GFDL ocean climate modelers during the past year include the following.

A/ MOM4p1 development: This code includes major upgrades to the MOM-code subsequent to the May2005 release of MOM4.0d. Included in MOM4p1 are

- multiple Eulerian (i.e. not isopycnal) vertical coordinates
- new tracer advection schemes
- updated open boundary conditions
- new physical parameterizations
- wrapper for the General Ocean Turbulence Model (GOTM)
- updated tracer options, including a prognostic ecosystem model
- enhance grid specification features (while still supporting older grid files)
- enhanced FMS infrastructure
- updated documentation and test cases
- new diagnostic features

This code is presently being used for global climate modeling in the one-degree and one-quarter degree class of models. It is a candidate for the next ocean code for use in GFDL's AR5 IPCC coupled climate model. A focused development cycle for the AR5 climate model begins at GFDL during the secondhalf of 2007. It is expected that this development will mature sometime in 2009.

B/ GOLD: The Hallberg Isopycnal Model (HIM) has been reformulated into the Generalized Ocean Layer Dynamics (GOLD), with primary development by Bob Hallberg and Alistair Adcroft. This code has updated algorithms for pressure gradient calculation, time splitting, and physical parameterizations. It has been configured as the ocean component in the GFDL CM2 coupled climate model. Its performance for coupled modelling will be assessed in parallel to the MOM4p1 development.

C/ GFDL ocean scientists continue to play a leading role in the CLIVAR Climate Process Teams (CPTs) on ocean mixing (gravity currents and eddy/mixed layers), which have entered their 5th and final year (ending 2008).

D/ GFDL climate modelers continue to push forward with the analysis of various climate related simulations using the AR4 coupled climate model. Such studies have emphasized work on climate variability, change, as well as impacts of climate on hurricanes.

E/ GFDL has moved forward with a coupled model assimilation project for use in ENSO forecasting as well as decadal prediction.

F/ GFDL earth system model development for AR5 IPCC assessment focuses mostly on extending the capabilities of the physical climate models to incorporate biogeochemical cycles on land, atmosphere, and ocean. Given the added cost of many new tracers and physical/chemical processes, this work is primarily being considered within the same physical ocean model configuration used for AR4 (i.e., one degree class ocean model). In addition to enhanced features for biogeochemical processes, the atmospheric component will see a refined vertical and horizontal resolution organized on a cubed sphere grid, along with the addition of many new physical and chemical processes. The decision to focus primarily on the atmosphere for enhanced resolution and physics is based on noting that the largest uncertainty in global climate models remains in the atmosphere.

A second development is ongoing within the ocean, to develop a one-quarter degree ocean component for studies focused on assessing the role of ocean eddies in global climate. This work involves the MOM4p1 ocean component, along with a refined resolution atmospheric model. The introduction of biogeochemical cycles is likely to remain too expensive for this ocean component, thus motivating a focus on physical processes in this model.

Update on global and large scale ocean modelling based on the NEMO system (A.M. Treguier, G.Madec)

NEMO (Nucleus for European Modelling of the Ocean) is a state-of-the-art modeling framework for oceanographic research and operational oceanography. It allows several ocean related components of the earth system to work together or separately. This framework is intended to be interfaced with the remaining component of the earth system (atmosphere, land surfaces, ...) via the OASIS coupler. NEMO is distributed under CeCILL license. The system is developed at CNRS in Paris (http://www.locean-ipsl.upmc.fr/NEMO), by a consortium of European institutions: CNRS, UK Met Office, ECMWF and Mercator-Ocean.

The present release of NEMO is version 2.3. It includes three engines (or components): OPA9 (ocean model), LIM2 (Louvain-la-Neuve sea-ice model), and TOP1, a transport component based on OPA9 tracer advection-diffusion equation (TRP) and a biogeochemistry model which include two components: LOBSTER and PISCES.

Work has been done in 2006-2007 as part of the MERSEA European project project to adapt the code to a broader number of scientific and operational applications, by providing more options for handling open boundaries (radiative open boundaries, flow relaxation scheme and flather condition), by implementing a variable volume option to allow the vertical coordinate to follow the displacements of the free surface, and by a full integration of the AGRIF grid refinement package in the standard version of the code.

New model developments planned ... (Gurvan?)

NEMO is used by a large number of research teams in Europe and elsewhere, and by three operational centers: Mercator-Ocean , the U.K. Met Office, and INGV (Tonani et al, 2007). Mercator-ocean has a new global 1/4° system since april 2007, http://www.mercator-ocean.fr/html/actualites/news/actu_psy3v2_en.html , which benefits from model improvements realized as part of the DRAKKAR project (Barnier et al, 2006). A new 1/12° North Atlantic model version is scheduled to replace the present prototype PSY2V2 at the end of 2007, and a 1/12° global model based on the tripolar ORCA grid is being developed as part of the MERSEA European project. Results are presented in the newsletter available on the Mercator-ocean web site. The collaboration of European operational oceanography centers is scheduled to continue, through the new project "MyOcean" submitted to the Framework 7 programme.

DRAKKAR is a network of scientific collaboration based on global and basin-scale configurations of the NEMO system. The collaboration has expanded recently: it involves French laboratories (LPO, Brest, LEGI, Grenoble, LOCEAN, Paris), Mercator-ocean, U.K laboratories (NOC Southampton, University of Reading), the IFM-Geomar in Kiel and KNMI in the Netherlands. There is also collaboration with S.I.O Moscow and the University of Alberta in Canada. The aim of the collaboration is the share model configurations, forcings fields, and coordinate sensitivity experiments (The Drakkar Group, 2007). The group meets twice a year. The next meeting, focussed on the global 1/4° model configuration, will take place in Brest in September. The DRAKKAR group is looking for funding sources at the European level (until now, groups have been supported by their respective national resources).

Coupled modelling activities with NEMO (Gurvan?)

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Ocean modelling activities in the East Asia Region
Report to the CLIVAR Working Group for Ocean Model Development
Submitted by Hiroyuki Tsujino (MRI-JMA), August 2007

1. Ocean modeling activities in Japan (by Hiroyuki Tsujino, MRI-JMA)

Acronyms:
CCSR: Center for Climate System Research, University of Tokyo
ES: Earth Simulator, JAMSTEC
FRCGC: Frontier Research Center for Global Change, JAMSTEC
JAMSTEC: Japan Agency for Marine-Earth Science and Technology
MRI-JMA: Meteorological Research Institute, Japan Meteorological Agency
NIES: National Institute for Environmental Studies
COCO: CCSR Ocean Component Model
MRI.COM: MRI Community Ocean Model

There are three broad categories of activities that have been the focus of ocean climate modelers in Japan for the past years: (1) updating oceanic components of global climate models for the next IPCC future climate projections, (2) developing systems for seasonal to inter-annual (or longer) climate predictions, (3) updating regional ocean models for use in regional marine environment forecasts.

1) Oceanic components of global climate models

The groups that plan to participate in the next IPCC assessment report are now updating their models.

The FRCGC plans to perform centennial time-scale climate projections using an Earth System model in collaboration with CCSR and NIES. The ocean component includes an NPZD ocean eco-system model and the required additional ocean chemistry. The COCO is used for the physical component. The horizontal resolution has not been fixed yet but will be around 1 degree. Projections will be performed on the ES.

The CCSR plans to perform decadal time-scale ensemble climate projections using a high-resolution (about 60 km for atmosphere and about 20 km for ocean) coupled model in collaboration with NIES and FRCGC. Its ocean model is COCO. The basic configurations of the oceanic component are the same as those of IPCC AR4 version, but some updates (ice thermodynamics, tracer advection scheme, use of tri-polar grid, etc.) are planned. Projections will be performed on the ES. (See also 2.)

The MRI-JMA plans to perform centennial time-scale climate projections using an Earth System model. The ocean component includes a bio-geochemical model. The MRI.COM is used for the physical component. The horizontal resolution has not been fixed yet but will be around 1 degree. Their main contributions to the IPCC are also extended to assessment of regional impacts by performing time-slice experiments using a 20-km AGCM (on ES) with CGCM-projected SST and a regional Atmosphere-Ocean coupled model with CGCM-projected side boundary conditions. The oceanic component (MRI.COM) of the regional climate model has 10 km horizontal resolution.

2) Seasonal to inter-annual (or longer) time-scale climate predictions

Since seasonal, inter-annual, and decadal time-scale climate predictions are often regarded as initial value problems, data assimilation systems are usually developed along with prediction models.

The MRI-JMA uses a quasi-global (75ºS-75ºN, 1 degree) ocean model coupled with TL95L40 AGCM for ENSO forecasting. The ocean model is MRI.COM and a 3D-VAR data assimilation system (MOVE; MRI multivariate ocean variational estimation system) is implemented. The performance of the coupled model with on-line 3D-VAR ocean model is now being investigated.

The group of **CCSR and FRCGC** plans to perform ensemble decadal predictions as described in 1. They are thinking about implementing the Ensemble Kalman Filter (EnKF) to obtain initial values for predictions.

A group in **FRCGC** is operating seasonal climate prediction system using SINTEX-F (Scale Interaction Experiment-FRCGC) in collaboration with European Scientists. Its ocean component is OPA and has 2-degree resolution. This system uses T106 AGCM and SST nudging as data assimilation.

3) Regional modeling and marine environment forecasting

The FRCGC is operating "ocean weather forecast" in the western North Pacific region (i.e., around Japan) as part of the Japan Coastal Ocean Predictability Experiment (JCOPE). This system uses a nested-grid 1/12º degree horizontal resolution model based on Princeton Ocean Model (POM). This system is recently implemented for operational forecast in the Fisheries Research Agency.

The MRI-JMA develops the forecasting system for the marine environment of the western North Pacific region. This system uses a nested-grid 1/10º horizontal resolution model based on MRI.COM. This system is replacing the current operational forecast system of the Japan Meteorological Agency. They are now performing 2-3 km horizontal resolution basin scale modeling for the North Pacific Ocean using ES.

The Research Institute for Applied Mechanics (RIAM) of Kyushu University is performing various marine environment modeling for the Sea of Japan using the model developed and maintained by them (RIAM Ocean Model (RIAMOM)). They are operating an ocean weather nowcast/forecast system for the Sea of Japan.

4) Earth Simulator

Resources of the ES are assigned to the qualified projects. Some of the resources are apportioned to the climate projection experiments as listed in 1.

The research groups of the Earth Simulator Center manage high resolution models such as OFES (H. Sasaki) and CFES (N. Komori) (OGCM and CGCM, respectively, for the ES).

Renewal of the ES is planned around 2009.

5) Model development

Some institutions and research groups (e.g., CCSR (H. Hasumi), MRI-JMA (H. Tsujino), RIAM (N. Hirose), Kyoto Univ. (Y. Ishikawa), and FRCGC (M. Tsugawa)) are developing and maintaining their own models. These models are basically MOM type z-coordinate models and use Arakawa-B grid. The COCO has velocity points at the coast, other models have tracer points at the coast. The COCO and MRI.COM are coupled with the AGCM of their institution (MIROC and MRI-CGCM, respectively).

6) CORE

The working group members are encouraging the Japan community to use CORE data sets for driving ocean-only (un-coupled) models. The group of CCSR and FRCGC is performing inter-annual forcing runs. The MRI-JMA is performing normal-year forcing runs.

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2. Ocean modeling activities for IPCC AR5 in China (with the help of Yongqiang Yu, LASG (the state key laboratory of numerical modeling for atmospheric sciences and geophysical fluid dynamics))

Much effort have devoted to development and application of OGCM during the past years in China, especially in two labs – the state key laboratory of numerical modeling for atmospheric sciences and geophysical fluid dynamics (LASG) and Beijing Climate Center (BCC). The recent model's development and application will be introduced for LASG and BCC as follows.

1) Recent model activities in LASG

In order to prepare IPCC AR5 and the other research projects in China, they are improving or planning to improve the LASG ocean model named LICOM in the following aspects:

(1) To improve solar radiation penetration scheme in the upper ocean
(2) To introduce a new mixing scheme (Canuto's scheme)
(3) To introduce diurnal cycle in surface forcing
(4) To increase horizontal resolution to 1/10 degree in 3 years
(5) To establish a data assimilation system based on LICOM
(6) To introduce biogeochemistry processes in LICOM

2) Recent model activities in BCC

To better understand climate variability in East Asia and improve the short-term climate prediction, an eddy-permitting OGCM is established based on MOM4. The OGCM spans the global range and it has 40 vertical levels. The horizontal grid spacing is 1 degree in longitude. Meridionally, the grid spacing is also 1 degree outside the tropics but decreases to 1/3 degree near the Equator for improved resolution of equatorial processes. Real forcing results show that simulated climatology is close to the observation. Interannual signals of the Pacific and Indian Oceans are reproduced reasonably in this model. In the next two years, carbon cycle and simple biogeochemical processes will be introduced to BCC ocean model in order to prepare the experiments of the IPCC AR5.

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3. Ocean Modeling Activities in KORDI (Korea Ocean Research & Development Institute)
(with the help of Cheol-Ho Kim and Young-Ho Kim, KORDI)

Global Ocean Modeling: KORDI global ocean model is based on the GFDL MOM3 which has a horizontal resolution of 0.5 degree from the Antarctic to 85°N and 30 vertical levels. For the physical parameterizations it adopts QUICKer scheme for tracer advection, Smagorinsky's diffusion scheme for momentum, G-M scheme for tracer and a partial cell topography scheme with corrected bottom topography especially for the several straits in the East Asian Marginal Seas (EAMS). It is integrated for 68 years at present with the restoring surface boundary condition using the Levitus climatology. Model MLD is compared with the observation for the model improvement.

Basin-scale Ocean Modeling: North Pacific Ocean model is being developed for the study of interaction between the EAMS and the Northwest Pacific based on MOM3. The horizontal grid resolution is enhanced from 1° in the North Pacific into 1/6° in the EAMS region. To obtain the realistic features for the regional distributions of tracer and current systems model responses are examined for the various surface forcing conditions such as restoring time scales for surface heat flux and resolution of wind stress dataset.

DA-ESROM : East/Japan Sea Regional Ocean Model based on the MOM3 (ver. 3.1) has been developed and the 3D-VAR data assimilation technique has been employed (hereafter, DA-ESROM). The background error covariance for the data assimilation has been simulated based on the correlation model with a generalized diffusion equation (Weaver and Coutier, 2001). The reanalysis through the DA-ESROM was performed from 1999 to 2002 for the Sea of Japan. For the present system, the SST from satellites and temperature profiles, taken by CREAMS (Circulation Research of the East Asian Marginal Seas), NFRDI (National Fisheries Research & Development Institute), JODC (Japan Oceanographic Data Center), and ARGO project, have been assimilated. Furthermore, the satellite altimeter data have been assimilated after validating by comparison with the observed sea level data at Ulleung and Dok Islands, Korea.

Hyoun-Woo Kang in KORDI is also working on a HYCOM based East Asian Marginal Seas Model for the ocean-typhoon interaction and regional impacts assessment of the climate change. The model domain covers the Northern Philippine Sea, the East China Sea, the Yellow Sea, and the Sea of Japan with the horizontal resolution of 1/12°. It has been configured as a stand alone regional ocean model and is still in a spin-up phase. This model will be extended to a coupled ocean-atmosphere model for the typhoon prediction system and the regional climate model.

There are four or five other modeling activities in Korea (mostly by individual effort) besides this report.

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