Ocean Model Development Panel

Achievements and Future plans

Prepared for pan-CLIVAR meeting in The Hague, July 2014 and CLIVAR SSG meeting in Moscow, November 2014

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Abstract

This document summarizes activities and achievements of the WCRP/CLIVAR Working Group on Ocean Model Development (WGOMD). These activities include (1) the Coordinated Ocean-ice Reference Experiments (CORE), (2) contributions towards ocean analysis of CMIP5 simulations, (3) development of the CLIVAR Repository for Evaluating Ocean Simulations (REOS), and (4) organization of seven international science workshops.

1 Introduction to the WGOMD

Since its start in the year 2000, the WCRP/CLIVAR Working Group on Ocean Model Development (WGOMD) has provided leadership on issues related to modelling the ocean as a component of the climate system, as well as guidance to various CLIVAR ocean panels. Although the Terms of Reference (TOR) have slightly changed over the 15 years of WGOMD, the present TORs are largely reflective of the original:

1. To stimulate the development of ocean models for research in climate and related fields.
2. To encourage investigations of the effects of model formulation on the results of ocean models, making use of sensitivity studies and intercomparisons.
3. To promote interaction amongst the ocean modelling community and between this and other communities through workshops and other activities.
4. 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, and to advise on the observational requirements of such studies.
5. To publicise developments in ocean models amongst the climate modelling community.
6. To collaborate with other activities in areas of overlapping responsibility.
7. To advise on ocean modelling and related issues and to report on its activities to the CLIVAR Scientific Steering Group.

1.1 Members

Past and present members of the WGOMD represent a cross-section of leaders in ocean modelling.

1. Claus Böning (Germany, chair 2000-2004)
2. Gokhan Danabasoglu (USA, co-chair 2009-present)
3. Helge Drange (Norway, co-chair 2007-present)
4. Stephen Griffies (USA, chair 2004-2007, co-chair 2007-2009)
5. Frank Bryan (USA)
6. Eric Chassignet (USA)
7. Enrique Curchitser (USA)
8. Katja Fennel (Canada)
9. Rüdiger Gerdes (Germany)
10. Richard Greatbatch (Germany)
11. Hiroyasu Hasumi (Japan)
12. Helene Hewitt (UK)
13. Anthony Hirst (Australia)
14. David Holland (USA)
15. Marika Holland (USA)
16. Helen Johnson (UK)
17. Yoshiki Komoro (Japan)
18. Simon Marsland (Australia)
19. Simona Masina (Italy)
20. George Nurser (UK)
21. Andreas Oschlies (Germany)
22. Anne-Marie Treguier (France)
23. Hiroyuki Tsujino (Japan)
24. David Webb (UK)
25. Michael Winton (USA)

1.2 Meetings

The WGOMD has met the following 12 times during its 15 year history.

- 2000: Miami, USA (RSMAS)
- 2001: Santa Fe, USA (LANL)
- 2002: Hamburg, Germany (MPI)
- 2003: Villefranche-sur-mer, France
- 2004: Princeton, USA (GFDL)
- 2005: Hobart, Australia (CSIRO)
- 2007: Bergen, Norway (Nansen Centre)
- 2009: Exeter, UK (Hadley Centre)
- 2010: Boulder, USA (NCAR)
- 2012: Venice, Italy (ISMAR)
- 2013: Hobart, Australia (CSIRO)
- 2014: Kiel, Germany (GEOMAR)

The WGOMD organized scientific workshops coincident with seven of these meetings (see Section 5).

2 Coordinated Ocean-ice Reference Experiments (CORE)

The first major achievement of the WGOMD was publication of a review paper summarizing the numerical and physical parameterization developments comprising the state-of-the-science ocean climate models (Griffies et al., 2000). This paper remains a standard reference for ocean model fundamentals, with 165 Web of Science citations and 274 Google Scholar citations in June 2014. Afterwards, the WGOMD focused on defining an experimental protocol for global ocean-ice simulations. In short, WGOMD aimed to address the following questions concerning global ocean-ice model simulations:

1. Is it feasible to derive and apply a common atmospheric and river state for use in running global ocean-ice models?
2. Is it feasible to define a broadly usable and scientifically valuable integration and sampling protocol for global ocean-ice simulations?
3. What is the scientific merit of comparing ocean-ice components of coupled climate models?

These questions were largely motivated by the following statement from Section 8.20.1 of the 2001 IPCC report (Houghton et al., 2001)

> *Our attempts to evaluate coupled models have been limited by the lack of a more comprehensive and systematic approach to the collection and analysis of model output from well coordinated and well designed experiments.*

In regards to ocean-ice models, WGOMD's answer to this charge is the CORE project proposed by Griffies et al. (2009b), which makes use of the Large and Yeager (2009) atmospheric state to derive surface boundary fluxes. In so doing, WGOMD provided an airmative answer to the first and second "feasibility questions" listed above. The third question concerning the scientific merit of such simulations remains part of the ongoing science of CORE simulations, with examples provided in this section.

2.1 CORE-I (CORE-Normal Year Forcing)

As proposed by Griffies et al. (2009b), the CORE protocol makes use of the Large and Yeager (2009) atmospheric state along with the NCAR bulk formula to derive turbulent fluxes (see Griffies et al. (2012) for details of the protocol). The surface salinity is generally damped to an observed climatology using methods largely open to the individual groups.

The Griffies et al. (2009b) paper compared seven models run for 500 years using CORE-I (repeating annual cycle) with the aim to assess and compare the long-term ocean-ice climate from a seasonally repeating atmospheric state. At the time, this comparison was unprecedented, and it remains a benchmark simulation that many groups use as a touchstone in their global ocean-ice model development (e.g., Tsujino et al., 2011; Sidorenko et al., 2011; Marsland et al., 2013).

A basic hypothesis of CORE simulations is that simulations would be very similar across the model suite, given their common atmospheric state. In contrast, the Griffies et al. (2009b) paper identified many simulation differences, such as those shown in Figure 1. Part of the reason for such differences is that the simulations are run for multiple centuries, allowing sufficient time for any systematic differences to grow, with these differences arising from numerical formulation distinctions, choices of physical parameterizations, and model resolution. Additionally, many differences arise from high latitude processes (e.g., convection, sea ice interactions), which are nonlinear and can impact deep into the ocean column.

In certain cases, the CORE-I comparisons helped model groups to identify mistakes that would have otherwise gone unnoticed. More scientifically, CORE-I identified basic questions and issues that became highly apparent after comparing simulations across a broad group of models. For example, Behrens et al. (2013) provides an in-depth analysis of instabilities associated with fresh water forcing in the high latitudes, with this study following on issues identified in Griffies et al. (2009b).

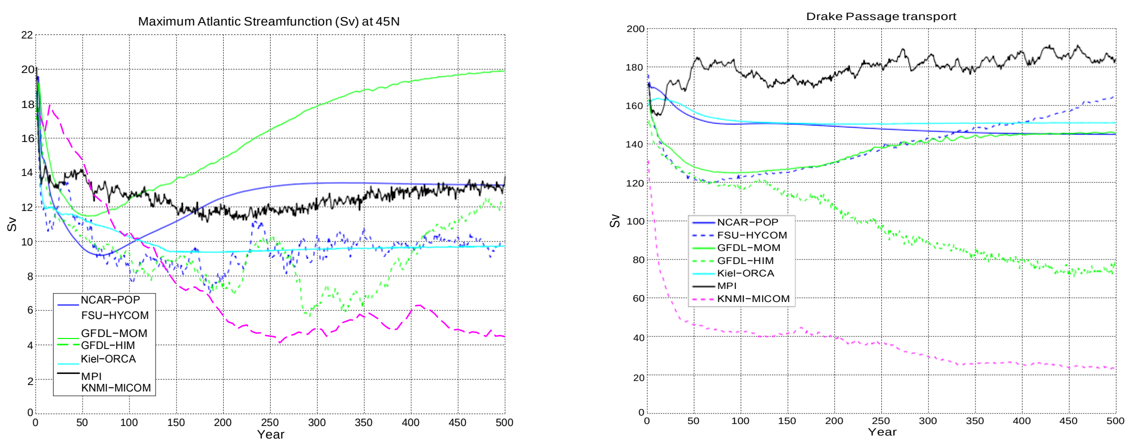

Figure 1: Left panel: Atlantic meridional overturning index (maximum streamfunction at 45^{o}N) from the seven CORE-Normal Year Forcing (CORE-NYF) simulations documented in Griffies et al. (2009b). Right panel: Drake Passage transport. Both figures are in units of Sverdrup (10^{6} m^{3} s^{-1}).

2.2 CORE-II (CORE-interannual forcing)

After working through the many challenges required to realize CORE-I, the WGOMD has focused more recently on the interannual CORE-II protocol. CORE-II makes use of the atmospheric state from Large and Yeager (2009), which extends over years 1948-2007, as well as the river runoff dataset from Dai and Trenberth (2002). Simulations extend over five repeating cycles of the 1948-2007 CORE-II state, with analysis focused on the final few decades of the last cycle. The remainder of the protocol largely follows the CORE-I approach.

Whereas the CORE-I simulations are largely of use for model development, the CORE-II "hindcast" simulations are motivated from both a model development perspective as well as one based on direct comparison to recent observations. Namely, CORE-II simulations provide a venue for the following activities:

- To evaluate, understand, and improve ocean models, in a way similar to CORE-I;
- To investigate mechanisms for seasonal, inter-annual, and decadal variability, and to evaluate the robustness of mechanisms across models;

- To complement data assimilation by bridging observations and modelling;
- To provide ocean initial conditions for climate (decadal) predictions.

CORE-II simulations have garnered a tremendous interest from modellers and analysts. In particular, there are now nearly 20 models having produced simulations that generally follow the CORE-II protocol. Furthermore, these CORE-II simulations have fostered analysis e↲orts focused on 10 research areas listed below. Plans are to publish each of these projects in a CORE-II special issue of the journal *Ocean Modelling* during 2014-2015. Figures 2 and 3 provide examples from the Atlantic mean and sea level projects. Both of these projects have been published, (Danabasoglu et al. (2014b), Griies et al. (2014)), with reference made to these papers for details of the corresponding scientific implications. Furthermore, a broader and more unified scientific assessment of these CORE-II projects will be considered when the various studies mature.

1. Arctic Ocean: (Wang et al., 2014)
2. Atlantic mean: (Danabasoglu et al., 2014b)
3. Atlantic variability: (Danabasoglu et al., 2014a)
4. Indian circulation: (Ravichandran et al., 2014)
5. Pacific circulation: (Tseng et al., 2014)
6. South Atlantic transport: (Sitz et al., 2014)
7. Southern Ocean water masses and sea ice: (Downes et al., 2014)
8. Southern Ocean eddy compensation and saturation: (Farneti and Collaborators, 2014)
9. Sea level trends: (Griies et al., 2014)
10. Watermass analysis: (Zika et al., 2014)

2.3 General comments regarding CORE

We here provide some historical context for CORE, as well as some points about why it took so long before the community converged in a manner suicient to coordinate multi-model comparisons.

2.3.1 Some history

Early oicial recognition of the interest in comparing global ocean-ice simulations goes back to 1996 within the CLIVAR and WOCE leadership. The issue of designing a common protocol was one of the major focii of the August 1998 WOCE modelling meeting at NCAR. The NCAR workshop did not recommend setting up a major centralized ocean model intercomparison (i.e., an OMIP). Instead, it recognized the importance of improving communication and coordination between modelling groups, as well as the value of readily available data sets for model initialization, forcing and evaluation. That is, the workshop recognized the diiculties inherent in merely “running global models and comparing their results.” Namely, there remained important research required prior to establishement of an OMIP. It was in this context that WCRP leadership established the WGOMD, whose central mandate was concerned with leading research e↲orts to design a common global ocean-ice simulation protocol.

Another important early milestone along the path towards CORE was the German-OMIP project (Fritzsch et al., 2000), based on a preliminary version of the Röske (2006) modification of ECMWF reanalysis. This project involved three research groups (Kiel, AWI, and MPI) with distinct model configurations based on two ocean model codes (MOM2 and HOPE). The German-OMIP project showed that comparison of global ocean-ice models was feasible and meaningful. Nonetheless, many questions remained concerning the chosen protocol. Community consensus suggested that further research was required before establishement of a wider comparison project.

The next key milestone along the path to CORE occurred at a joint meeting in Villefranche-sur-mer between the WGOMD and the CLIVAR Atlantic panel in 2003. Here, Bill Large from NCAR expressed his intention to produce an atmospheric dataset of use for global ocean simulations based on NCEP and supported by NCAR. Publication of the Large and Yeager (2004) technical report provided the basis for the CORE-I project, and Large and Yeager (2009) later facilitated CORE-II.

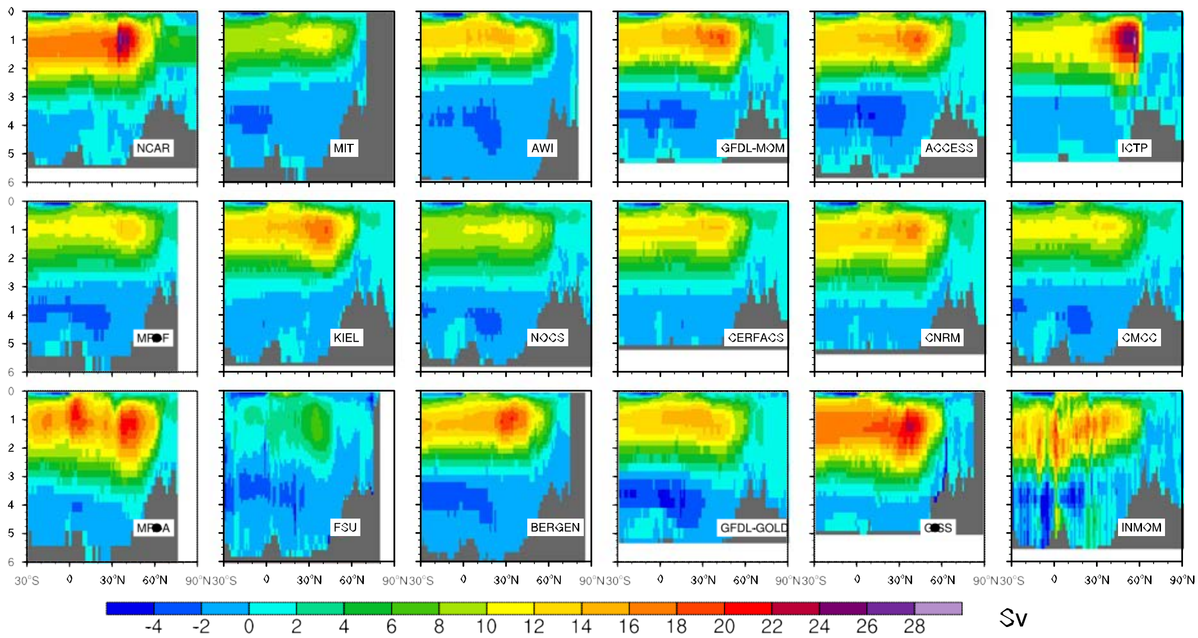

Figure 2: An example of results from the Atlantic mean CORE-II paper of Danabasoglu et al. (2014b) (see their Figure 3). Shown here is the time-mean Atlantic meridional overturning circulation as a function of depth (km) and latitude. The positive and negative contours indicate clockwise and counter-clockwise circulations, respectively. In MIT, AWI, MRI-F, MRI-A, FSU, BERGEN, and GISS, the AMOC distributions do not include the high latitude North Atlantic and/or Arctic Oceans, and hence are masked. Time-mean refers to the 20-year means for years 1988-2007, corresponding to simulation years 281-300.

2.3.2 Some reasons for the long development time

It is noteworthy that a goal so simple to state ("compare global ocean-ice model simulations") took roughly 15 years to realize (1996-2009). This time scale for CORE-I, and the ongoing CORE-II efforts, reflects certain nontrivial issues related to global ocean-ice simulations.

- The global ocean-ice system exhibits long-time scales for equilibration (Stouffer, 2004; Danabasoglu, 2004), adding great expense to simulations aimed at assessing interior ocean climate behaviour.
- There are critical high-latitude feedbacks precluded when removing an interative atmosphere from the ocean-ice system, with the absence of these feedbacks introducing unphysical model instabilities (Griffies et al., 2009b; Behrens et al., 2013). Relatedly, it remains a research question whether more robust salinity/water boundary conditions, such as proposed by Hallberg and Gnanadesikan (2006), are suitable for model comparisons.
- It is a nontrivial effort to develop an atmospheric state suitable for global ocean-ice models. Notably, use of unmodified reanalysis products leads to unacceptable drifts on the decadal to centennial time scales due to global imbalances. The renanalysis products also contain major biases that would lead to problems with the global simulations. Hence, the state-of-the-art method for producing a suitable atmospheric state requires extensive expert judgements from those with experience working with both ocean models and atmospheric products. Thus far, the only other comparable method for running global ocean-ice simulations is that produced by Brodeau et al. (2010) for use in the DRAKKAR

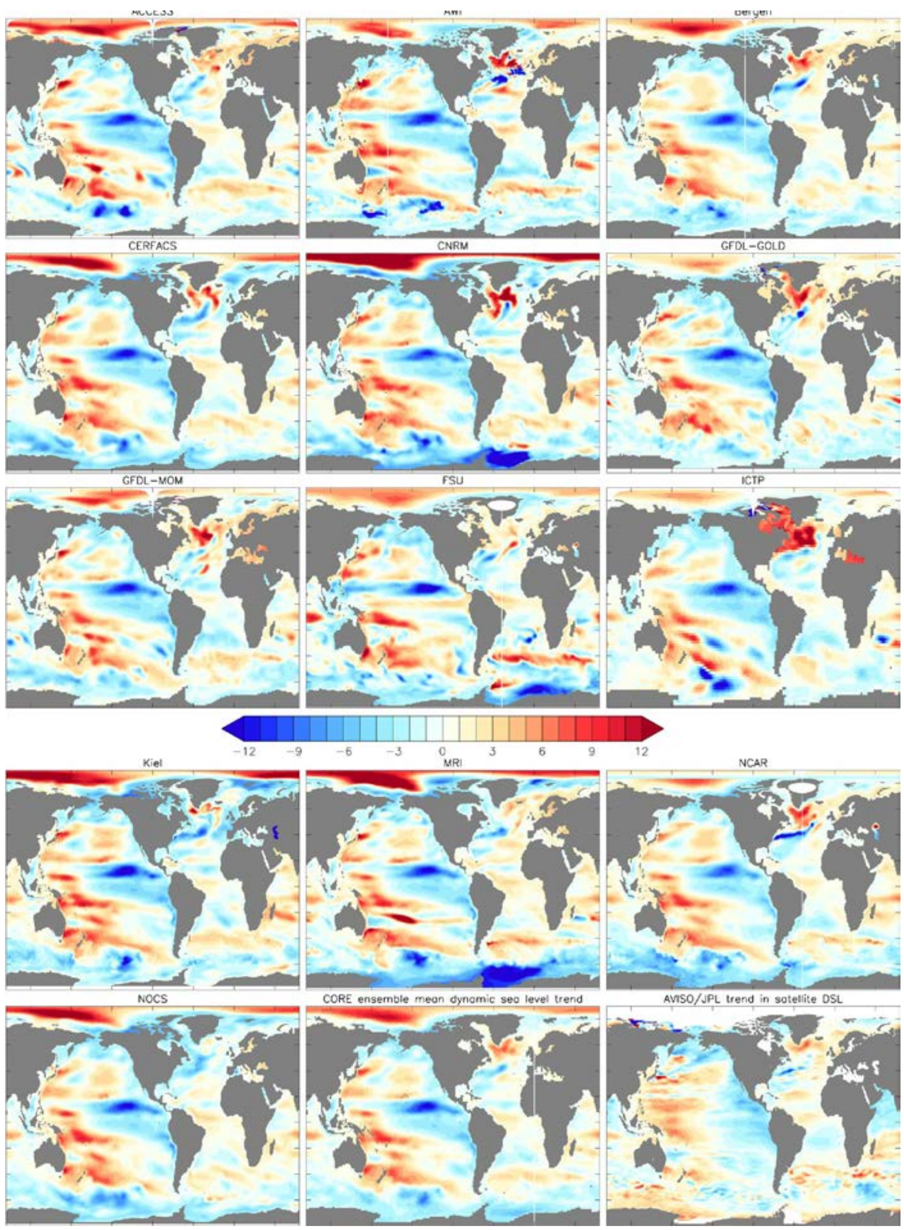

Figure 3: An example of results from the CORE-II sea level paper of Griffies et al. (2014) (see their Figure 18). Shown here is the linear trend in annual mean dynamic sea level (mm/yr) for the years 1993-2007 as computed from the fifth cycle of CORE-II simulations. Shown are results from the individual models as well as the ensemble mean computed using all simulations. Also shown are observation-based estimates of the trend based on the AVISO analysis of satellite measurements (podaac.jpl.nasa.gov/dataset/AVISO_L4_DYN_TOPO_1DEG_1MO).

consortia. The task of maintaining and updating these atmospheric states is onerous and poorly supported by funding agencies.

- The global ocean-sea ice modelling community is small relative to the community of scientists running global atmospheric models. Development time is correspondingly longer.

As emphasized by Griffies et al. (2007) and Griffies et al. (2009b), CORE simulations do not resolve the many problems related to forcing global ocean-ice models. Rather, CORE highlights diiculties, and provides a means to lift disparate modelling e↲orts onto a common plateau from which alternative experimental designs and forcing data sets can be systematically explored.

2.3.3 Evolution of CORE

CORE is an evolving process, with the initial protocol proposed in Griffies et al. (2009b) under constant scrutiny. In particular, at the 2014 Kiel WGOMD workshop on high resolution modelling, and subsequent WGOMD meeting, proposals were discussed regarding the following topics.

- Salinity/water boundary condition: The question of how to force the surface salinity/water remains problematic due to the extreme sensitivities of high latitude processes to the details (Behrens et al., 2013). One option is that suggested by the regional eddying simulations from Hallberg and Gnanadesikan (2006), with tests of this approach ongoing within the DRAKKAR consortia (Carolina Dufour, personal communication 2014).
- Interactive atmospheric state: Should CORE consider the use of a simplified interactive anomaly atmosphere, such as that proposed by Deremble et al. (2013)? In principle, an interactive atmosphere will remove many of the limitations of the Griffies et al. (2009b) methods. However, care should be taken to allow for some observation-based control over the climatology, allowing for the hindcast features of CORE to remain. The Kiel group is presently testing the feasibility of using this “CheapAML”.
- Role of the ocean in transient climate change: Kostov et al. (2014) provided a method to assess the transient sensitivity of climate using forced ocean-ice models. Some participants in the workshop expressed an interest in testing these ideas with potential for broader comparisons.
- CORE-III (water hosing): Additional interest remains in developing a common water perturbation protocol, sometimes called CORE-III. The original proposal was put forward by Gerdes et al. (2005, 2006), aimed at assessing the oceanic response to large scale melting scenarios for Greenland. Analogous water perturbations were considered by Stammer (2008) and Lorbacher et al. (2012) for Antarctic melt.
- Mesoscale eddying comparisons: There remain relatively few mesoscale eddy-active (25 km or finer) global ocean-ice models. One avenue to support collaboration and knowledge sharing is to consider a CORE-like comparison with focus on aspects of mesoscale eddy-active simulations. To support this activity, one may wish to refine the atmospheric state used to force the models, given the relatively coarse one-degree resolution used in Large and Yeager (2009). E↲orts to develop a finer version of the CORE atmospheric state remain in discussion.

These discussions and proposals suggest that the future of CORE-like model comparisons is rich and exciting.

3 Contributions to CMIP

WGOMD led in writing a document that articulated a scientific rationale for saving a suite of physical ocean fields for CMIP5 (Griffies et al., 2009a). The perspective taken was that of physical ocean scientists aiming to enhance the scientific utility of model simulations contributing to CMIP5. As discussed in Griffies and Danabasoglu (2011), the level of diagnostics requested by WGOMD was far larger than the CMIP3 ocean diagnostics. However, it is important to note that WGOMD provided three levels of priority, with most of the newer variables not at the highest level. Furthermore, new variables related to subgrid scale parameterizations were largely requested only for the final 20 years of the historical simulations. The WGOMD, or more precisely its new incarnation as the Ocean Model Development Panel, will play a leadership role in developing the CMIP6 ocean diagnostic request, with the CMIP5 request providing a solid foundation for moving forward.

4 Repository for Evaluating Ocean Simulations (REOS)

In the early-days of WGOMD, there was a dearth of coordination between modellers and observationalists. Among the problems that modellers had was how to identify sanctioned datasets for use in evaluating simulations. To assist in resolving this limitation, WGOMD developed the CLIVAR Repository for Evaluating Ocean Simulations (REOS). This web site aims to facilitate the research community's access to

- basic datasets and analyses/syntheses products;
- metrics for evaluating variability and processes including input by the CLIVAR basin panels;
- guidance on ocean model validation;
- tools available for the community for ocean model data analysis;
- a comprehensive bibliography of papers, linked to the online articles where possible.

In order to make more use of this web site within CLIVAR, we recommend that it be incorporated into a broader pan-CLIVAR repository of sanctioned datasets, methods, projects, etc. Doing so will facilitate coordination across the observation-based and model panels. It will also leverage input from a broader group of CLIVAR scientists than available just within the WGOMD.

5 Scientific workshops organized by WGOMD

Since 2004, WGOMD has organized or co-organized seven scientific workshops aimed at communication, collaboration, education, and furthering the careers of young scientists. We display a photo montage of the workshops in Figure 4. These workshops generally gathered 100-150 top ocean scientists together for 2-3 days of provocative interactions. All sessions were plenary, with discussions and questions encouraged, thus making the workshops a true working group where ideas and debates flourished.

5.1 Princeton, 16-18 June 2004: Assessment of a New Generation of Ocean Climate Models

This workshop facilitated a dialogue between modellers, theorists, and observationalists on the physical integrity of the CMIP3 global ocean and climate models, with particular focus on articulating how best to move forward over the next decade to improve simulation realism. A thorough summary of the workshop, with abstracts of talks, is provided in the workshop report

> *Report of the CLIVAR Workshop on Assessment of a New Generation of Ocean Climate Models, 16-18 June 2004, GFDL Princeton USA*, November 2004 ICPO Publication Series No. 83 WCRP Informal Report No. 16/2004.

5.2 Hobart, 9-10 Nov 2005: Southern Ocean Modelling

This workshop brought together ten international experts on Southern Ocean physics, circulation, modelling, and observations for two days of presentations and discussions. The first day of the workshop was devoted to "Observations and Dynamics" and the second day to "Processes and Climate Change". A thorough summary of the ten presenations, along with recommendations, is provided in the workshop report

Figure 4: A photo montage from the seven WGOMD scientific workshops.

Report on the WGOMD Workshop on Southern Ocean Modelling, ICPO Publication Series No 102, WCRP Informal Report No. 7/2006. Informal Report No. 16/2004.

5.3 Bergen, 24-25 Aug 2007: Numerical Methods in Ocean Models

The numerical methods workshop fostered the maturation of ocean models by supporting enhanced collaboration between model developers and analysts. It did so by bringing together nearly 100 of the world's top ocean modellers and theoreticians. 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 and physical parameterizations. A thorough workshop report is provided by

Summary Report of the CLIVAR WGOMD Workshop on Numerical Methods in Ocean Models, ICPO Publication Series No.128 WCRP Informal Report No. 4/2008.

5.4 Exeter, 27-29 April 2009: Ocean Mesoscale Eddies: Representations, Parameterizations, and Observations

This workshop educated the research community regarding the importance of mesoscale eddies in the World Ocean. It helped to identify best practices for parameterizing ocean mesoscale eddies in coarse resolution climate models, and fostered discussions on various research avenues for improved parameterizations. The workshop helped to evaluate the ability of state-of-the-science numerical models to accurately represent the ocean mesoscale in eddying simulations typically run with a reduced reliance on parameterizations.

In addition to its many scientific achievements, the workshop honoured the seminal works of Gent and McWilliams (1990) and Greatbatch and Lamb (1990). After more than 20 years, these works remain the touchstone for studies of mesoscale eddy parameterization and theory. Furthermore, the workshop represented a memorial to the tireless and intellectually penetrating work of Peter Killworth, who passed away in January 2008.

This workshop was reported in *CLIVAR Exchanges* by Griffies (2009). Additionally, *Ocean Modelling* published 15 peer-reviewed articles in a special issue related based on the topic of the workshop, with an introduction to the special issue provided by Griffies (2011).

5.5 Boulder, 20-23 Sept 2010: Decadal Variability, Predictability and Prediction: Understanding the Role of the Ocean

This workshop focused on the role of the ocean in decadal phenomana and prediction. It helped to assess how well the ocean models and ocean syntheses reproduce observed decadal variability. Understanding and evaluation were primary concerns for this workshop, where e↵orts were made to identify robust oceanic internal and forced variability, and to explore the underlying physical mechanisms. In so doing, the workshop helped to identify shortcomings of ocean models, syntheses, and observations for decadal variability studies.

Sessions covered the following topics: (A) observed and simulated oceanic decadal variability; (B) decadal climate variability and the role of the ocean; (C) initialization, predictability, and predictions; (D) the role of ocean synthesis and hindcasts; (E) climate observations required for understanding predictions.

5.6 Hobart, 18-20 Feb 2013: Sea-Level Rise, Ocean/Ice-Shelf Interactions, and Ice Sheets

This workshop advanced the state-of-knowledge of projections of future sea level by focussing on two major scientific challenges. Firstly, what is the global sea-level rise contribution from the stability (or otherwise) of ice-sheet mass exchanges with the oceans. Secondly, what is the regional signature of sea-level rise associated with the mass redistribution of both the changing ocean and ice sheets. Together, these components of sea-level rise inform knowledge of potential coastal impacts, and contribute to the understanding of a topic currently drawing intense scientific and societal interest. 10 research articles based on presentations at this workshop were published in volume 62 of *CLIVAR Exchanges* (2013).

5.7 Kiel, 7-9 April 2014: High Resolution Ocean Climate Modelling

The workshop brought together major climate modelling groups at the forefront of high-resolution ocean modelling, facilitating education and collaboration. Mesoscale eddies are certainly the most spectacular and most energetic dynamics that emerge in ocean models at 25 km resolution or finer, but the workshop was not restricted to mesoscale eddies, with discussions on all climate-relevant processes that are deeply impacted by ocean model resolution. These include representation of western boundary currents and major fronts, air-sea coupling in upwelling areas, exchanges with marginal seas, processes on continental shelves, and emerging modes of air-sea interactions. This workshop will be reported on within a future edition of CLIVAR Exchanges.

6 Closing comments

WGOMD has remained at the center of major ocean model development and application activities since 2000. Notable among its achievments include its published review of ocean model developments in 2000, with that paper holding up well over the course of the past 15 years. Perhaps its most prominent achieivement is development of the most widely used global ocean-ice model comparison activity (CORE), whose scientific utility continues to expand. WGOMD organized seven science workshops whose outcomes provided tangible coordination and collaboration amongst a broad number of ocean and climate scientists, as well as valuable opportunities for young scientists to enter the field. WGOMD played a leading role in CMIP5 ocean analysis, writing a benchmark document articulating the scientific rationale for saving the requested variables. It has also provided the community with an authoritative web site (REOS) from which ocean modellers are guided in their quest to determine the best observation-based datasets to evaluate simulations.

Under the new CLIVAR organization, WGOMD has been renamed the Ocean Model Development Panel (OMDP). The Terms of References for the OMDP presently remain as those for WGOMD, though the panel will evolve as the scientific needs of CLIVAR evolve.

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