CLIVAR WGOMD High-Resolution Ocean Climate Modeling Workshop

7-9 April 2014

1. Venue: Hosted by GEOMAR Helmholtz Center for Ocean Research at the Steigenberger Conti Hansa Hotel, Kiel, Germany

2. Scientific Organizing Committee:

Anne Marie Treguier (chair), Laboratoire de Physique des Océans, France
Claus Böning (local organizer), GEOMAR Helmholtz Center for Ocean Research, Germany
Frank Bryan, National Center for Atmospheric research, U.S.A.
Bunmei Taguchi, Japan Agency for Marine – Earth Science and Technology, Japan
Helge Drange (WGOMD co-chair), University of Bergen, Norway
Gokhan Danabasoglu (WGOMD co-chair), National Center for Atmospheric Research, U.S.A.
Anna Pirani (CLIVAR ICPO), Southampton, U.K.

3. Proposed attendees, including likely number:

Representatives of ocean (and climate) modeling groups from around the world, working on high-resolution ocean modeling. To facilitate meaningful information exchange, the workshop will be limited to about 50 invited participants.

4. Aims and Objectives:

The workshop will bring together international scientists, including early-career researchers, who are at the forefront of high-resolution ocean modeling for climate. With the recent increases in computational power, more and more modeling groups are conducting high-resolution ocean-ice and / or fully coupled earth system simulations. Most of these activities appear to be quite independent despite the fact that groups are encountering very similar challenges and trying to come up with similar solutions. Moreover, there is a need to understand new sensitivities and processes emerging in high-resolution ocean simulations. Thus, an important goal of our workshop is to foster collaboration between these groups to expedite progress.

High-resolution ocean modeling is needed for many scientific and societal applications, including regional climate information regarding sea level and extremes. These are among the WCRP Grand Challenges (GCs) and CLIVAR Research Opportunities (ResOps). Thus, the workshop will make important contributions to the goals of several WCRP GCs, particularly the ones on Regional Climate Information; Sea-Level Rise and Regional Impacts; and Science Underpinning the Prediction and Attribution of Extreme Events. Specifically, these GCs seek regional information on small spatial scales, requiring improved understanding of physical processes on these scales. Similarly, the workshop contributes to the goals of the CLIVAR Research Opportunities (ResOps) on

Intra-seasonal, Seasonal and Inter-annual Variability and Predictability of Monsoon Systems; Decadal Variability and Predictability of Ocean and Climate Variability; Trends, Nonlinearities and Extreme Events; Marine Biophysical Interactions and Dynamics of Upwelling Systems; and Dynamics of Regional Sea Level Variability. These CLIVAR ResOps complement WCRP Grand Challenges. We believe that high resolution ocean climate modeling will contribute to improving representation of some key physical processes, e.g., air-sea interaction and feedbacks, oceanic mesoscale, upwelling, and boundary currents, that are at the heart of these ResOps.

The workshop will allow the major climate modeling groups that are at the forefront of high-resolution ocean modeling to meet and take stock of the most recent advances. Mesoscale eddies are certainly the most spectacular and most energetic dynamics that emerge in ocean models at 1/4° resolution or higher, but the workshop will not be restricted to mesoscale eddies: we will discuss 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. The workshop will be organized in four types of sessions (see section 10 for further details): i) theoretical and process-oriented sessions to foster discussions on the dynamics behind the emerging behaviors of coupled climate models when a high-resolution ocean component is used; ii) an exchange session ("ongoing work") to allow the groups to present their more recent advances to each other and promote closer collaboration; iii) a technical session to share expertise about the challenges brought about by high-resolution ocean modeling – addressing, among others, numerical methods, massively parallel computing, storage strategies, and post-processing; and iv) a session on opportunities that high-resolution ocean models offer for the regional downscaling of global climate.

5. Relevance and/or benefits to U.S. CLIVAR:

The membership in the WGOMD of model developers of several key international climate modeling centers (from the U.S., especially NOAA/GFDL and NCAR) and workshop representation by key modeling groups (from the U.S., DoE's LANL, MIT, NCAR, and GFDL) provide an ideal international platform for discussing current high resolution ocean climate modeling progress and challenges, and for sharing ideas on how to move forward in the related modeling and model development efforts at GFDL, NCAR, DoE LANL, and MIT and across the international community.

The workshop goals and objectives are strongly linked to the new U.S. CLIVAR Science Plan (December 2013). Specifically, the workshop is relevant to the U.S. CLIVAR goals on *understanding the role of the oceans in observed climate variability on different timescales* and *improve the development and evaluation of climate simulations and predictions*. The U.S. CLIVAR has identified four research challenges: i) decadal variability and predictability; ii) climate extremes; iii) polar climate; and iv) climate and ocean carbon / biogeochemistry. We believe that development, use, and analysis of high-resolution ocean models are beneficial to all four U.S. CLIVAR research challenges as they seek improved understanding of ocean physics and regional information. A few

examples include the role of air-sea interactions in impacting Atlantic Meridional Overturning Circulation and decadal variability and predictability; the impacts of eddies on Southern Ocean stratification and mixing, affecting polar climate; and the effects of eddies on oceanic carbon uptake and the role of ocean resolution on marine ecosystem studies. Finally, the workshop is highly relevant to two of the U.S. CLIVAR cross-cutting strategies. Namely, *model development* and *process studies*. The latter explicitly identifies the need for eddy-resolving ocean simulations to inform planning of process studies.

6. Nature and format of meeting:

The workshop will have 6 or 7 sessions over three full days. The session lengths are not expected to be all equal. To accomplish one of our key goals, namely to foster collaboration between the groups to expedite progress, we will devote enough time in each session for meaningful discussions. Our tentative format for the workshop is

Day 1: - Introduction and review of current understanding (session 1)
- Ongoing Work – State-of-the-Art Simulations (session 2)

Day 2: - Ocean Physical Processes and Their Parameterization (session 3)
- Technical Challenges (session 4)

Day 3: - Interaction With Atmosphere and Cryosphere (session 5)
- Downscaling (session 6)
- Meeting conclusion: proposition of a new experimental Design (session 7)

Some details of these sessions are as follows:

Session 1: Introduction and Review of Current Understanding
Where are we coming from? Speakers will summarize the main conclusions and open questions from recent working groups, workshops, and relevant research programs.

1a. *Mesoscale Eddies and Climate*: How do eddies interact with the large-scale ocean circulation? How well are they represented in current models? State of the art as presented at the 2009 WGOMD workshop in Exeter and the recent literature.

1b. *Ocean-atmosphere interaction on frontal- and meso-scales*: How do air-sea fluxes over ocean fronts and eddies impact the larger scale / lower frequency climate system, both in the atmosphere and ocean? Summarize outcomes from U.S. CLIVAR Working Group on Western Boundary Currents, recent workshops (e.g., Boulder August 2013) and recent literature.

1c. *The Resolution Dependence of Climate Biases, Variability, and Sensitivity in Comprehensive Earth System Models*:What do we know from available CMIP type integrations?

1d. *New Modes of Coupled Variability:* What new or different climate phenomena / variability might we expect when both the atmosphere and ocean are turbulent? Guidance from theory and idealized studies.

Session 2: Ongoing Work – State-of-the-Art Simulations
Representatives from different climate modeling efforts will present their current state-of-the-art simulations, the scientific questions they are applying high-resolution simulations to, and the main challenges they see to progress in high-resolution modeling. Each will list the questions they would like discussed during the meeting? Most will be from groups involved in coupled system modeling, but some may be from groups focused on ocean- or atmosphere-only simulations that are addressing relevant questions. Invited participants will include representatives from the following groups: CESM (both NSF and DoE efforts), GFDL, MIT, NASA GISS, FSU HYCOM, Hadley Center, University of Tokyo, JMA/MRI, JAMSTEC/ESC, DRAKKAR, GEOMAR, AWI, ACCESS/AusCOM, MPI Hamburg, IPSL, CNRM-CERFACS, EC-Earth, and CMCC.

Session 3: Ocean Physical Processes and Their Parameterization
The shift to higher resolution means that some processes previously parameterized or neglected become explicitly represented, while at the same time there are different requirements for subgrid scale closures. This session will address the challenges and opportunities for improving the representation of physical processses in high-resolution models, and possibly using high-resolution simulation results to improve parameterizations used in coarser models. Some specific topics to be covered are:

- Eddies and their transports: upscale and downscale cascades and parameterizations. Scale adaptive parameterization - how to parameterize the unresolved part of the mesoscale energy spectrum; what are the effects of the submesoscales? Do we know how to parameterize them? Are the effects on larger scales captured by current eddy parameterization in lower resolution models?
- Diapycnal mixing: vorticity-internal waves interactions; Can we do better at diapycnal mixing parameterizations when the mesoscale is resolved?
- Western boundary current dynamics
- Passages and overflows, marginal seas
- Shelf-deep ocean interaction
- Role of internal (intrinsic) ocean variability in generating low frequency climate variability

Session 4: Technical Challenges
While many groups are using the same codes for eddy-parameterized and eddy-resolved modeling, a number of groups are developing new modeling frameworks for multi-scale modeling. How do we parameterize, test, and verify ocean models with a typical resolution of, say, 0.2° to 0.5°?. What are the lessons learned so far and remaining challenges? The volume of output from high-resolution models can be overwhelming. How can we address the data-glut? Some specific topics to be covered are:

- Numerical methods and alternative grids
- Special requirements for coupling high-resolution global models
- High-performance computing issues
- Data management, pre- and post-processing tools

Session 5: Interaction With Atmosphere and Cryosphere

Some topics that we plan to cover include:

- Processes of air-sea interaction and air-sea fluxes in the presence of mesoscale eddies
- Air-sea coupling in upwelling areas
- Processes in polar regions: sea ice and ice sheets
- Ice – ocean coupling and instability issues at high resolution

Session 6: Downscaling and Upscaling
Can high-resolution ocean models be used to downscale climate scenarios for particular regions of interest? How do different methods compare? Topics to be considered include:

- Nesting, regionally adaptive grids.
- Is it possible to use atmospheric anomalies from low-resolution climate simulations to force ocean-ice models?

Session 7: Meeting conclusion: proposition of a new experimental Design
There has thus far been little coordination of experimental design for high-resolution modeling compared to the relatively well-established protocols for CMIP and CORE experiments. Are there common points of reference that can be exploited to help advance the state-of-the-art and facilitate sharing among groups?

- Methodologies to explore sensitivities, what is different when using eddy-resolving ocean models? Are ensemble strategies required? How would we design sensitivity tests such as freshwater hosing experiments?
- Observations for evaluating eddy-resolving simulations. Identifying common metrics for assessing high-resolution simulations.
- New CORE protocol(s)

7. Deliverables:

A key outcome of the workshop is the interaction and information exchange that it will facilitate among various groups that are working on different aspects of high resolution ocean climate modeling.

Workshop participants will be encouraged to disseminate the outcomes of the workshop through a planned Special Issue of CLIVAR Exchanges. A workshop report will also be included in this special issue.

A major ongoing activity of the WGOMD is an inter-comparison of ocean models subject to CORE inter-annual atmospheric forcing, which builds on previous WGOMD efforts. So far, this activity has been largely confined to simulations with coarse resolution ocean models. In the workshop and the subsequent WGOMD panel meeting, we will explore developing a protocol for COREs for use in high-resolution ocean modeling.

We also plan to provide input to the next phase of CMIP, i.e., CMIP6, regarding high-resolution ocean climate modeling.