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Summary of actions, decisions and recommendations

1. Under the AR4 activity, the requirement to interpolate ocean model data from coupled runs on regular grids has needed considerable effort. More consideration needs to be given to the problems of data management for ocean models. This issue to be followed up with the WGCM Climate Simulation Panel **(Action: S Griffies, ICPO)**.
2. The WGOMD welcomed the concept of a US community ocean model working group noting both its distinct role within the US and its complementarity to the role of WGOMD. It should however have a more distinct label than e.g. US WGOMD to enable its distinct character to be recognised. **(Action: E Chassignet)**.
3. Ensure all groups are informed about the changes in the configuration of CORE-I runs **(Action: S Griffies)**.
4. In terms of issues associated with the Large and Yeager forcing data set for CORE runs, the group recommended:
   a. Extension of the GFDL database of Interanually Varying Forcing (IVF) is useful and should be done as soon as possible. This should be release 1.1; anything further should be 2.0
   b. Bill Large make the judgment on whether to use new/extended radiation data, which had arrived.
   c. That a move to geographically varying tropical humidity corrections be tackled as part of a version 2 dataset.
   d. That CliC be asked to advise on whether suitable humidity data are available to investigate the issue of the potentially too high a corrected humidity over the Arctic region. **(Action M Holland)**
   e. The issue of the mean of the IVF not being the same as the Normal Year Forcing (NYF) needs resolution.
   f. That the proposed corrections to wind direction, based on Quickscat data be applied to the NCEP dataset.
   g. That the 5% reduction to the solar radiation forcing should stand, given the support for this from TAO & PIRATA measurements.
   h. That if possible the global ocean heat flux imbalance for NYF be the same as that for the IVF though it was recognized that adjustments could, in any case, be made during runs.

   (Action: M Holland to advise Bill Large of the group's recommendations)
5. Circulate the Atlantic Panel metrics document to WGOMD (Action S Griffies) and put onto the WGOMD web page **(Action: ICPO)**. Write to the Atlantic Panel to thank them and work with them on pointer to observational datasets **(Action: S Griffies and others)**. Wait before taking forward with other panels at this stage beyond e.g. presentation to the Pacific Panel **(S Griffies).**
6. The WGOMD are supportive of a move to use of the Large and Yeager forcing for AOMIP runs. **(Action: R Gerdes to explore with AOMIP)**
7. If the wider community is to be involved in analysis of CORE runs (especially CORE-II runs, then a more robust data management system needs to be in place. Discuss issues of dataset management for coordinated experiments with WGSIP and consider options for the CORE-II runs. **(Action: S Griffies, ICPO)**.
8. Streamfunction as well as Eulerian velocity needs to be output from ocean models as a Streamfunction routine so that the overturning circulation can be constructed. This needs addition of an extra field. The WGOMD endorsed this suggestion but recognised that this may be an issue for submission of data to the AR4 datasets. There is a need to check with the WGCM Climate Simulation Panel, and through them with PCMDI as to whether a request for an additional data field can still be submitted **(Action S Griffies, ICPO)**.
9. Members of the group to examine the WGOMD webpages (http://www.clivar.org/organization/wgomd/wgomd.php) and send additional material for inclusion to the ICPO **(Action: All)**. Dr Griffies and the ICPO to consider in particular was additional material is required to give a fuller description of CORE activities overall **(Action S Griffies, ICPO)**
10. Discuss membership renewals/changes with the CLIVAR SSG **(Action: S Griffies, ICPO)**.
11. The next meeting of the group to be held 28-29 August 2007, just prior to the Open Science Conference on "Polar Dynamics: Monitoring, Understanding and Prediction" (Bergen, Norway 29-31 August 2007) and if possible in association with a meeting of the CliC Arctic Climate Panel **(Action M Holland to explore with the ACP)**. Dr Drange to explore hotel block booking arrangements **(Action: H Drange)**.

12. Participants to submit short accounts of presentations **(Action: All)**.

1. Welcome and opening remarks

The 6th session of the CLIVAR Working Group on Ocean Model Development (WGOMD) was held at CSIRO Marine and Atmospheric Research, Hobart, Tasmania, Australia on the 8th and 11th November 2005, spanning a WGOMD Southern Ocean Modelling Workshop held on 9th -10th November at the same location (see separate report). Dr Stephen Griffies (Chair of WGOMD) and Dr Trevor McDougal (Director, CSIRO Marine and Atmospheric Research, Hobart) opened the session and welcomed Working Group members, invited experts and local participants. A list of participants can be found at Annex A and the agenda for the meeting at Annex B. Dr Howard Cattle, Director of the International CLIVAR Project Office (ICPO), also extended his welcome on behalf of CLIVAR and the ICPO.

2. Report from the CLIVAR SSG (H Cattle)

Dr Cattle provided an outline of the World Climate Research Programme (WCRP). CLIVAR (Climate Variability and Predictability) is one of the four current projects of WCRP. The others are the Global Energy and Water Experiment (GEWEX), Climate and Cryosphere (CliC) and Stratospheric Processes and Climate (SPARC). Other WCRP activity takes place through the Earth System Science Partnership (ESSP) projects on the Carbon Cycle, Water, and Food and Fibre. The overall objectives of WCRP are “to determine to what extent climate can be predicted” and “the extent of human influence on climate”, aiming at the goal of greatly improved understanding of the role of climate in the total Earth system. WCRP acts, through its projects to coordinate international research effort on physical aspects of climate. It links in particular to the International Geosphere Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and Diversitas, an international programme of biodiversity science. These programmes, with WCRP, form the partners of the ESSP.

Dr Cattle then gave a brief overview of the WCRP’s Coordinated Observation and Prediction of the Earth System (COPES) Strategic Plan established by the Joint Scientific Committee (JSC) for WCRP. The aim of the Plan is “to facilitate prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society”. As a strategy it aims to integrate the efforts of the core projects of WCRP (GEWEX, CLIVAR, CliC and SPARC) and the major modelling activities under the joint JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and the WMO Commission for Atmospheric Sciences/WCRP Working Group on Numerical Experimentation (WGNE). It will do this in particular through the establishment of pan-WCRP Task Forces of which the Task Force on Seasonal Prediction, led by CLIVAR’s Working Group on Seasonal to Interannual Prediction (WGSIP) is the first.

The WCRP Strategic Plan seeks to synthesise the ongoing observational and modelling activities of all relevant WCRP components against the key concept of “seamless prediction” of the total physical climate system from weeks to decades. To facilitate this a WCRP Modelling Panel (WMP) and a WCRP Observations and Assimilation Panel (WOAP) have been established in order to (a) provide overall coordination of WCRP modelling observational and assimilation activities, (b) facilitate the interactions of WCRP with external groups and organisations and (c) provide oversight of data management in WCRP.

Within WCRP, CLIVAR’s mission is “to observe, simulate and predict the Earth’s climate system, with focus on ocean-atmosphere interactions enabling better understanding of climate variability, predictability and change, to the benefit of society and the environment in which we live”. CLIVAR science and implementation plans developed through the mid 1990s, with CLIVAR implementation starting in earnest in 1999, following the International CLIVAR Conference held in Paris from 2-4 December 1998. CLIVAR is being implemented through its panels and working groups, facilitated, on a day-to-day basis by the activities of the ICPO. More detail can be obtained from the CLIVAR website at www.clivar.org.

A major event of 2004 had been the 1st International CLIVAR Science Conference, which was held in Baltimore, USA from 21-25 June. The theme of the conference had been around “understanding and predicting our climate system”. The conference, which had 640 registered attendees from 56 countries, was the largest WCRP conference ever. There were 14 major sponsors with the conference organisation being led by Dr David Legler of the US CLIVAR Office. The purposes of the conference were to review the highlights of the first 5 years of CLIVAR implementation and more importantly to determine future priorities and new directions for understanding and predicting climate. In particular it provided input into the CLIVAR self assessment which was the focus of CLIVAR SSG-13 (Baltimore, 27-29 June 2004), held immediately following the conference. Dr David Anderson (ECMWF) had acted as reviewer for modelling, covering the activities of WGOMD.

As a key outcome of the assessment, SSG-13 agreed that CLIVAR will work to focus more on the 4 major themes of ENSO, monsoons, decadal modes of variability and the thermohaline circulation and anthropogenic climate change. Workshops would be run on one of the four themes annually. SSG meetings would also be restructured with each panel and working group asked to report, in particular, against i) its contributions to the themes and annual workshops; ii) activities related to regional assessment of predictability and variability in global model outputs; iii) cross panel and working group links and iv) Terms of Reference (TORs). These were reflected in the current outline agenda for CLIVAR SSG-14 planned to take place in Buenos Aires, Argentina from 19-22 April 2006

From a WGOMD perspective, SSG-13:

- Recognised the WGOMD role in performing the WGOMD assessment of ocean model performance in ocean-only experiments but felt it would also be important for WGOMD to focus on the role of the ocean as a component of the coupled climate system and on how improvements in ocean models impact on coupled models,
- Requested WGOMD (with the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP)) to work with CLIVAR's Global Synthesis and Observations Panel (GSOP) on how they will interact in the future, in particular on what observation simulation experiments are feasible to give guidance on observation system design.
- Requested efforts be made to strengthening of the links between WGOMD and the CLIVAR ocean basin panels, in particular in regional assessment of WGOMD global model coordinated experiments.

These items would all need consideration and action by the WGOMD.

3. Report from the CLIVAR Working Group on Coupled Modelling (H Cattle)

Dr Cattle next outlined the outcomes of the WGCM meeting, which had taken place at the Met Office, Exeter, UK from 3rd - 5th October 2005. It was followed by the first meeting of the WCRP Modelling Panel at which he had made a presentation on behalf of WGOMD. A key WGCM agenda item had been to review progress with IPCC/CMIP activities. These had motivated the formulation of the largest international global coupled climate model experiment and multi-model analysis effort ever attempted. The activity, which started in October 2003, had been coordinated by the WGCM Climate Simulation Panel (Panel members: G Meehl, C Covey, M Latif, B McAvaney, J F B Mitchell, R Stouffer). Fourteen modeling groups from around the world were participating with 21 models; considerable resources have been devoted to this project by PCMDI, which has a key role in data management.for the activity. More than 27 TeraBytes of model data had been archived so far.

Results from analyses of the multi-model dataset were presented by 125 scientists at a workshop convened by US CLIVAR and hosted by IPRC (University of Hawaii) March 1-4, 2005. By the time of the WGCM meeting, over 200 papers had been submitted to peer-reviewed journals containing results from analyses of the multi-model runs. This provided direct feed-in to the IPCC AR4 assessment process. To date, there are over 400 analysis projects registered at PCMDI; more are being added every week. This is more than triple the most optimistic estimate for participation. Overall, this is the largest, most comprehensive, highest profile and, arguably, most successful project ever organized by WGCM.

Other WGCM agenda items had covered:
- Developments within WCRP (JSC, COPES, WMP etc, CLIVAR, CliC, GEWEX)
- Progress with regional modeling.
- Scenarios for IPCC AR5 and WGCM influence
- Reports from modelling groups

- Data management issues (for which it was agreed to promote approach used for AR4, including CF conventions for metadata.)
- The next CMIP activity (20th century forcing experiments for detection/attribution, anthropogenic vs. natural, proposed by David Karoly)
- Other WGCM activities (the Cloud Forcing Model Intercomparison Project (CFMIP), forcing scenarios, model initialisation (short review of current options), climate change detection, paleo modelling (PMIP))
- Links to Earth System Modelling (Carbon cycle, ESSP/Global Carbon Project, C4MIP, biosphere modelling)
- Interactions with THORPEX

The joint session with WMP had included:

- Long discussion on concept of "seamless prediction" (a key element of the WCRP Strategic Plan)
- Reviews of modelling activities from WGNE; the GEWEX Modelling Panel; CLIVAR (WGCM,WGSIP,WGOMD); CliC, the WCRP Task Force on Seasonal Prediction
- Monsoon Modelling activities
- A report from the WCRP Observations and Assimilation Panel (WOAP)
- Discussion of the Atmospheric Model Intercomparison Project (AMIP)

The WGOMD presentation had included:

- The Pilot Ocean Model Intercomparison Project (P-OMIP) and the outcomes of the WGOMD Workshop "Evaluating the ocean component of IPCC-class models", leading to concept of Coordinated Ocean Reference Experiments (CORES).
- Outline of CORES (including mean, interannually varying and freshwater perturbation experiments)
- A short report on the joint WGOMD/CLIVAR Atlantic workshop on Atlantic Thermohaline variability.

A particular question arising for WGOMD from the discussion were the compatibility of the WGOMD freshwater perturbation experiments to the CMIP water hosing experiments? There was also substantial discussion on the topic of model resolutions required for climate experiments. In response to the question on the freshwater experiments, the WGOMD noted that there were differences, making the two activities complementary (see also Section 6.4).

In discussion of model intercomparison issues, the group commented in particular on the difficulties of assessing ocean-only model runs where the focus often turns to the issue of the forcing fluxes. It was noted that there were not too many ocean assessment activities under the AR4 activity with members commenting that a particular problem had been the requirement to interpolate ocean model data onto regular grids. It was felt that there needed to be more effort overall in working through the problems of data management for ocean models.

Action – Follow up on issue of submission of data for the ocean component of coupled model runs with the WGCM Climate Simulation Panel (S Griffies, ICPO)

4. Proposal for a US Working Group on Ocean Model Development (S Griffies, E Chassignet)

Dr Griffies outlined the new structure of US CLIVAR following its reorganisation. Under the new structure, opportunities have been made for the establishment of short-term working groups focussed around specific topics. Dr Chassignet had therefore raised the question within the US modelling community as to whether there was a need for a US Working Group on Ocean Model Development. He noted that a variety of ocean circulation numerical models are presently used in the US for climate studies and that ocean model development has a long history of being primarily the fruit of individual efforts, rather than a cohesive community effort. The limitations of this approach, he felt, are increasingly apparent and this mode of development is no longer viable. The time has come therefore for the development of ocean modeling capabilities to become a coherent community effort. There is now general agreement among ocean modelers that generalized vertical coordinates are desirable for skillful simulations of the ocean (Griffies et al., 2000).

There are well known deficiencies of each of the commonly used vertical coordinates with implication that an appropriate generalized vertical coordinate ocean model would minimize the coordinates' liabilities, while providing the flexibility to tailor the model for specific applications. Development of a Hybrid Ocean Modelling Environment (HOME) is seen as a first step in that direction.

HOME would provide a versatile, open-source, community Ocean Modeling Environment using a generalized hybrid vertical coordinate and Dr Chassignet outlined the key features and vision for developing this. He defined a "Modeling Environment" as a uniform code comprising a diverse collection of interchangeable algorithms and supporting software from which a model (a specific collection of algorithms – e.g. OPA, MOM, HYCOM, …) and a specific configuration, including parameter settings, geometry, forcing fields, etc. (e.g. CLIPPER, DRAKKAR) can be selected. This would include the ability to couple to atmospheric models.

Dr Chassignet proposed to create a US WGOMD to reflect on the above and to propose concrete steps on how one should act. In the short term, a consolidation and evaluation of the diverse range of existing practice will be of tremendous value, while in the longer term, the community must systematically explore options for extending the skill and applicability of ocean models. Such a working group would need to include users as well as developers. The proposed terms of reference would be:

- To evaluate and quantify the diverse range of existing modeling practice,
- To assess what the climate community really needs while ensuring excellence and diversity,
- To propose concrete steps to ensure that the ocean modeling activities becomes a truly coherent community effort.

Consistent with the requirements for US CLIVAR Working Groups, the proposed group would have a short life span, i.e., less than 2 years with the main goal to gather community input via a workshop and provide a summary for further action.

In discussion the WGOMD raised a number of questions about the proposed HOME activity for which it is essential that the concept of a "modeling environment" is kept distinct from that of a model per se**. Overall the group welcomed the concept of a US community ocean model working group noting both its distinct role within the US and its complementarity to the role of WGOMD. It should however have a title other than US WGOMD to ensure it's distinct character is recognized. (Action: E Chassignet)**

5. Reports from WGOMD committee members on modelling activities in their sector

During this part of the meeting, presentations were made on:

Modelling activities for IPCC AR4 in Japan (H Hasumi)
Ocean modeling activities at the Frontier Research Centre for Global Change, Japan (H Hasumi)
Ocean model activities at GFDL, USA, Jun 2004-Nov 2005 (S Griffies)
Ocean modeling activities in the UK (H Banks)
Australian ocean modeling activities (M England)
Ocean modeling activities in Canada (submitted manuscript – R Greatbatch)
Ocean general circulation model development in Norway (H Drange)
Community climate system model (CCSM) ocean modeling activities (M Holland)
Update on the development of NEMO (Nucleus for European Modelling of the Ocean, a numerical platform for ocean modeling) (A-M Treguier)

Written accounts of these will be found at Annex C

6. Coordinated Ocean-ice Reference Experiments (S Griffies)

Dr Griffies began with a history providing background to the present concept of CORE summarized as follows:

- Miami 2000: German OMIP presented to WGOMD by R Gerdes. AWI (MOM3) and MPI (HOPE). Both z-models (MOM3 B-grid and HOPE C-grid). Roeske's normal year forcing derived from modified (balanced) ECMWF dataset. 100 yrs. Modest simulation differences. Motivated pilot-OMIP.

- Santa Fe 2001: Discussed metrics for ocean models and P-OMIP. Groups still not ready for running P-OMIP.
- Hamburg 2002: P-OMIP protocol proposed, and a few participants committed. Some climate centres (e.g., CSIRO, GFDL, and Hadley) not participating due to IPCC (AR4) pressures.
- Villefranche 2003 and EGU in Nice: P-OMIP results presented by Frank Bryan. Bill Large announces NCAR work to produce a dataset with both normal year and interannual forcing for 40+ years, based on a mixture of satellite products, NCEP reanalysis, and "corrections". Interannual forcing useful for hindcast simulations of interest to CLIVAR panels. NCAR to produce data and GFDL to support web distribution.
- Princeton 2004: Further discussion of OMIP and forcing datasets. P-OMIP declared a "failure" due to scientific disinterest. CORE proposed by Frank Bryan as an alternative philosophy to OMIP, with focus on research questions. Idea received favourably by WGOMD, using Large and Yeager (2004) forcing.

A preliminary outline for a paper based on CORE-I results from ORCA and GFDL (see below) has been developed. Plans are to complete the manuscript in 2006, to include participation from CCSM (NCAR), GFDL, HYCOM (Miami), MICOM (KNMI), and ORCA (Kiel) models. Thus much remains to be done but progress is being made with the CORE concept.

Forcing for CORE experiments is provided through the Large and Yeager (2004) dataset containing:

- Normal year and interannual varying data contain fields on a spherical grid of 192 longitude x 94 latitude points
    - Annual mean river runoff
    - monthly varying precipitation (12 time steps per year),
    - daily varying shortwave and longwave radiative fluxes (365 time steps per year, and so no diurnal cycle and no leap years)
    - six-hourly varying meteorological fields (4 x 365 x 43 time steps per year with no leap years).
        - 10m air temperature,
        - humidity
        - zonal wind
        - meridional wind
        - sea level pressure
- Details of access to the dataset, Fortran code for the bulk formulae, the Large and Yeager (2004) technical report, support code (e.g., mapping scheme for river runoff), and release notes can be found at http://nomads.gfdl.noaa.gov/nomads/forms/mom4/CORE.html which can also be reached through the WGOMD web pages on the CLIVAR home pages.

The dataset is an evolving one; discussions of ongoing issues, and of a potential new version, will be found below.

3 CORES had been proposed:

- CORE-I: normal year forcing with quasi-equilibrium simulations
- CORE-II: interannual forcing
- CORE-III: normal year forcing with fresh water perturbation (Gerdes, Hurlin, and Griffies 2005 Ocean Modelling in press)

6.1 CORE-I (ocean-ice simulations with repeating annual cycle); manuscript presentation (S Griffies)

Dr Griffies summarised the position with CORE-I experiments as follows:

- CORE-I involves runs of ocean-ice models with repeated annual forcing from Large and Yeager

(2004).

- A GFDL/NCAR mini-comparison using different bulk formulae revealed unacceptable differences in fluxes realized with the same ocean state. The conclusion is that models should use same bulk formula when aiming to compare--contrary to the original plans.
- 100 years of P-OMIP was too short for meaningful water mass comparisons, though many metrics (e.g., thermocline and tropical circulation) can be compared after 100 years.
- 500 years provides more meaningful water mass comparisons; this is the target for the CORE-I manuscript simulations. All participants had agreed to provide 500 years.
- Goals of planned CORE-I manuscript:
  - o Introduce Large and Yeager (2004) and outline some difficulties with datasets.
  - o Relate difficulties designing ocean-ice simulations: ambiguities and important details that can lead to nontrivial differences.
  - o Illustrate simulations from a suite of models and highlight issues with salinity/water forcing: e.g., some model's THC collapses without nontrivial salinity damping, yet some (at least one) do not. Why? Likely not answered in this paper.
  - o Present pedagogical discussions and recommendations for design and analysis of ocean-ice simulations, including outline of some useful metrics.
  - o To reach both experienced global climate modellers, but especially new modellers (there are many now picking up global models for first time).
  - o Articulate issues related to global ocean-ice simulations to facilitate intelligent experiments and model comparisons. That is arguably part of WGOMD's mandate. Try to provide such information within a peer-review paper.
  - o Aim to submit to the journal Ocean Science (David Webb) ~mid-2006 after significantly more thorough analysis of the five models involved. More participants would be welcome.

It was agreed that there was a need to ensure that all groups are informed about changes in the configuration for CORE-I runs **(Action: Dr Griffies)**. In discussion of the forcing, Dr Boening noted the most critical choice is that for the freshwater restoration in high latitudes. Dr Holland noted that NCAR carries out restoring under ice for interannually varying runs and raised the question of whether this should be dome for the CORE-I runs also. This might induce a difference with other model runs and needs to be followed up (**Action: Dr Holland**). Dr Drange stated that he had been trialing various approaches to freshwater flux correction and wished to see others carrying out such simulations to determine the optimum way of doing this. In discussion it was agreed that this would not be a set of experiments within the context of the present CORE-I runs, but that provision could be made for the CORE-II interannually varying runs. See also the discussion in Section 8.

6.2 Simulations with CORE-II interannual Large and Yeager forcing and a discussion of the dataset issues, etc.

6,2,1 Kiel experiences (C Boening)

Dr Boening talked about experiences of the Kiel ocean modelling group with the interannual Large and Yeager forcing, i.e., CORE-2 hindcasts and sensitivity experiments using ORCA2 and ORCA05. A focus of the analysis was on the interannual-decadal variability in the tropical Pacific. While the mean SSTs exhibit the typical cold bias signature in the central Pacific, the sea surface temperature (SST) variability for both model versions is in very good agreement with data, e.g., for the Nino3-region. Sensitivity experiments demonstrate that a significant part of the equatorial SST variability is related to the changes in the equatorward transports of thermocline water associated with the subtropical-tropical cells (STCs); in both models the STC transports across 10S/10N drop by about 14 Sv during the last 4 decades, a trend similar to that inferred from hydrographic data (McPhaden and Zhang, Nature 2002, GRL 2004). Transport variations simulated for the tropical Atlantic were compared with the results of previous, higher-resolution FLAME experiments subject to forcing based on NCAR/NCEP-products (Huettl and Boening, JGR, submitted 2005). Whereas strong model-model differences were found on seasonal to interannual time scales, the decadal variability (i.e., time scales longer than about 5 yrs.) was similar in all model cases, with a robust, positive trend of about 2 Sv over the last 4 decades. Further analysis is underway to determine e.g. the relationship between the (inter-) decadal changes in tropical transports and SST, and the variability in the deep meridional overturning circulation (MOC) which is also, in all model cases, characterized by an increase (from the late 1960s or early 1970s into the 1990s): obviously, the availability of a wider spectrum of model realizations will greatly aid in the derivation of robust conclusions about underlying dynamical mechanisms.

6.2.2 NCAR experiences (M Holland)

Dr Holland outlined the CORE-II ocean-only and ice-only experiments carried out at NCAR. In summary the protocol used was as follows:

- Initialized with Levitus/PHC, no motion
- 4x43 year cycles
- Salinity Forcing
    - Precipitation factor used
    - Weak restoring with piston velocity of 50m/4yrs globally
    - Specified ice-ocean flux from coupled run

Frazil ice formation salinity flux

The purpose of the ocean-only experiments was to provide information on:

- Attribution of upper ocean biases in CCSM3, a number of which had been identified (Large and Danabasoglu, 2005)
- Ocean variability and process studies (Yeager and Large, 2004; Capotondi et al., 2005)

Ice-only experiments had been run which used initial ice conditions from a previous ice-only run with the ocean heat flux convergence specified (held fixed) from a CCSM3 coupled integration. The purpose of these runs was to:

- Examine issues/difficulties in validating sea ice models
- Perform simulations with different forcing datasets,
- Perform simulations with variations in parameter values
- Quantify uncertainty due to model forcing versus model physics

6.3 Forcing dataset issues (M Holland)

Dr Holland introduced a number of issues associated with the Large and Yeager forcing dataset which had been compiled by Bill Large with input from data users. Firstly it was noted that new/extended data are available. Interannually varying forcing (IVF) data through 2004 are available at NCAR and should be checked out in early 2006. Future CCSM IVF runs will be run through 2004. There is no intention of recomputing normal year forcing (NYF) with data to 2004, but an issue for the panel was whether the GFDL IVF database should be extended. Overall, **the group agreed that extension of the GFDL IVF database to 2004 was useful and should be done as soon as possible. This should be release 1.1; anything more should be version 2.**

The group was further informed that new/extended radiation data had just arrived containing "replacements" for the previous data for January 1997 – June 2001. These may have some minor effects in terms of global means (up to a few tenths W/m^2) but there are some large flux values changes (> 100 W/m^2) for a few grid cells (primarily land areas) for a few flux components." In consideration of whether the "replacement" data should be used, **the group agreed that it would be best for Bill Large to make the judgement**.

In terms of tropical humidity, it was noted that a comparison of TOA and NCEP humidity (Jiang et al., 2005) had shown results fundamentally different than earlier comparison (Wang and McPhaden, 2000) on which tropical corrections were based. In the tropical East (but not the West) Pacific, the new study was consistent with the Southampton Oceanography Centre (SOC, now National Oceanography Centre, Southampton (NOCS)) dataset. The new comparison and SOC data suggest that humidity corrections should NOT be zonally uniform (as is currently done). Consideration was being given to exploring an objective alternative SOC-based correction that depends on both latitude and longitude. The question is, what should be done for CORE? Should we work with relative or specific humidity? In consideration of this issue, **the group agreed that this should be tackled as part of a version 2 dataset (see below).**

For Arctic humidity, Elizabeth Hunke (LANL) believes that the corrected humidity is still too high over Arctic sea ice. She is trying to gather some data sets to quantify the possible problem, so that the correction could be improved. The question is whether there are any suitable Arctic humidity data available. Overall **the group felt that s question should be addressed in the first instance to CliC (Action: M Holland as a member of the CliC Arctic Climate Panel).**

The mean windstress in NYF is based on 1958-2000. However the Southern Ocean has a trend in zonal windstress to increasing westerlies. If ACC transport is tuned to winds from later years, a weaker ACC will result when forced with NYF. Should the mean NYF be based on 1958-2000, 1983-2000, 1958-2004 or 1983-2004 therefore? In consideration of this, **the panel agreed that the key issue was that the NYF should have the same as the mean as that of the interannually varying forcing. At present this is not the case. This needs resolution.**

In terms of wind direction, NCEP wind direction has been compared to QSCAT. There are 2 small regions of systematic bias; in the ITCZ regions of central N Pacific, along the Pacific coast of S America. A possible correction being considered is to adjust the mean and standard deviation of the wind direction to:

$$N' = \underline{Q} + (s_Q/s_N)\,(N-\underline{N})$$

so N' (the corrected NCEP direction) is a function of the mean QSCAT direction and the ratio of the standard deviations. The question is whether the corrections should be applied? If so, how? Globally? In discussion, the group pointed to the importance of the wind for the global circulation. **Overall, they agreed that the corrections should be made**, noting the areas affected are small in size.

It was noted that a 5% reduction made to the solar radiation is supported by measurements from TAO and PIRATA buoys in the tropical Pacific and Atlantic. **In the absence of other evidence, it was felt that these should stand.**

It was further reported that, NYF, when used with observed SST, has a global ocean heat flux imbalance of 5 Wm^{-2} compared to 1 Wm^{-2} for the IVF (1958-2000). **The group considered that though it would be best if both were the same, though adjustments could in any case be made during runs.**

It was agreed that Dr Holland would feed back the panels views to Bill Large (**Action: M Holland**). An additional issue which had been raised by Dr W Hazeleger (KNMI, the Netherlands and CLIVAR Atlantic Panel co-chair) was that of negative vales of specific humidity on a spectral grid. The group viewed this as an interpolation problem. Feedback to Dr Hazeleger would be provided by email.

6.4 CORE-III (thermohaline perturbation experiments) (R Gerdes)

Most coupled climate models agree that the thermohaline circulation will slow down due to increased fresh water input in high northern latitudes under increasing greenhouse gas concentrations in the atmosphere (IPCC, 2001; Schmittner et al., Geophys.Res.Lett., in press). However, the magnitude of the trend differs among models, the sensitivity of the ocean component being the prime candidate for this uncertainty. To assess the sensitivity of IPCC class global ocean models WGOMD proposed a "water hosing" perturbation experiment as a third Coordinated Ocean-ice Reference Experiment (CORE). The design of he experiment is presented in Gerdes et al. (2005) and first results are given in Gerdes et al. (2006). An important feature that distinguishes the design from the corresponding CMIP protocol for water hosing experiments is the source of anomalous fresh water fluxes around Greenland. We anticipate that several fresh water fluxes (strengthened hydrological cycle, reduction of Arctic sea ice and liquid fresh water reservoirs, and melt water from Greenland) will all lead to increased fresh water content in the boundary currents around Greenland. Models that aim at simulating these possible future developments must be able to cope with fresh water flux anomalies that are concentrated in these boundary currents.

A serious problem of perturbation experiments in stand-alone ocean-sea ice models is their sensitivity to the form of the surface boundary conditions. The feedbacks involving the atmospheric response to changes in oceanic heat transport are especially important. For example, ocean models under mixed boundary conditions can exhibit unrealistic sensitivity with respect to surface fresh water flux anomalies. The high sensitivity is caused by the positive salinity advection feedback. In nature and in fully coupled models this feedback is counterbalanced by the negative temperature advection feedback that is suppressed under mixed boundary conditions. The temperature advection feedback requires a response in atmospheric temperatures to changes in ocean heat transport. The dependence of OGCM sensitivity on the surface boundary conditions is a general problem as it affects all ocean variability experiments to some degree. Ocean modellers need to find a solution to this problem.

It seems to be necessary and worthwhile to develop and improve simple atmospheric components to be used in ocean-sea ice experiments with variable or anomalous forcing. The CORE experiments can provide a common experimental framework to compare and validate such efforts.

References

Gerdes, R., S.M.Griffies, and W.J.Hurlin, 2005: Reaction of the oceanic circulation to increased melt water flux from Greenland – a test case for ocean general circulation models, CLIVAR Exchanges, 33, 28-31

Gerdes, R., W.Hurlin, and S.M.Griffies, 2005: Sensitivity of a global ocean model to increased run-off from Greenland, Ocean Modelling (in press)

7. Reports from other panels and committees:

7.1 CliC/CLIVAR/SCAR Southern Ocean Panel (S Rintoul)

Dr Rintoul began by noting that the panel was currently undergoing a substantial overturn in its membership with some refocusing of interests. The panel had held a very successful workshop on “Modes of Southern Hemisphere Variability”, immediately followed by a panel meeting (Cambridge, UK, June 2005). Papers from the Workshop could be found in the October 2005 issue of CLIVAR Exchanges. Dr Rintoul summarized the current status of observational programmes for the Southern Ocean, details of which can be found on the Southern Ocean Panel’s web pages at http://www.clivar.org/organization/southern/CLIVAR_CliC_Obs.html). He noted the panels’ activities in developing the International Polar Year (IPY, 2007/8) “Climate of Antarctica and the Southern Ocean (CASO) proposal which has the following 5 key themes tackling key unknowns:

- Antarctica and the Southern Ocean in the global water cycle
- Southern hemisphere teleconnections
- Climate processes at the Antarctic continental margin
- Climate – ecosystem – biogeochemistry interactions in the Southern Ocean
- Records of past Antarctic climate variability and change

CASO has been planned to:

- Obtain the first circumpolar snapshot of the Southern Ocean, including physical, ecological and biogeochemical properties.
- Measure the circumpolar extent and thickness of Antarctic sea ice through an annual cycle for the first time.
- Observe the sub-ice ocean circulation, water mass properties and biological distributions

The IPY observing system for the Southern Ocean was seen as comprising:

- Synoptic multi-disciplinary transects
- Measurements to derive sea ice volume
- An enhanced sea ice drifter array
- Ocean circulation under sea ice
- Enhanced Southern Ocean Argo
- Enhanced meteorological measurements
- Ice cores from high accumulation rate coastal sites
- Process studies

There were plans under CASO to use acoustically tracked floats under ice, enhanced moorings and, under the Synoptic Antarctic Shelf-Slope Interactions Study (SASSI) planned for 2007/8, for CTD/ADCP sections. Just how much funding would be available for activities overall was not clear. A disappointing development had been the failure of Cryosat.

As yet CASO does not have a strong modelling component. However Dr Rintoul encouraged the modelling community to become involved in IPY from a Southern Ocean perspective.

7.2 Indian Ocean Implementation Panel (S Wijffels)

This presentation on "Development of the Moored Buoy Array for Climate and the Integrated Observing System" was given by Dr Wiiffels on behalf of Dr Mike McPhaden (NOAA/PMEL) and Dr Gary Meyers (CSIRO Marine and Atmospheric Research and Chair of the IOC GOOS/CLIVAR Indian Ocean Panel). Indian Ocean climate science drivers are the need for improved description, understanding and ability to predict:

- Seasonal monsoon variability, intra-seasonal oscillations and far field impacts
- Monsoon <=> ENSO <=> Indian Ocean Dipole interactions
- Warming trends since the 1970s
- The unique Indian Ocean circulation

To do this requires the development of an in situ, integrated Indian Ocean observing system, the design and justification of which had been the key element of the Indian Ocean Panel's work over the past 2-3 years. The recently published plan ("Understanding the Role of the Indian Ocean – Implementation Plan for Sustained Observations", http://eprints.soton.ac.uk/20357/01/IOP_Impl_Plan.pdf) identifies XBT lines, Argo floats and surface drifters as standard elements, a basin-scale array of moorings as a key new element and additional measurements from biological sensors, boundary arrays and process studies. The draft strategy for the Indian Ocean moored buoy array foresees 30 TAO/Triton buoys plus 5 ADCP and 8 flux moorings. A start had been made on the array deployments by the USA and India with planned deployments by Japan. An Indian Ocean Moored Buoy Data Assembly Centre (DAC) has been set up, hosted at PMEL with PMEL and JAMSTEC as initial contributors and with mirror sites outside the US (e.g. INCOIS in India). The DAC is modeled after the TAO/ TRITON and PIRATA data processing and dissemination systems. As a matter of policy, all data from the array will be freely and openly available without restriction. Major issues that have to be resolved to fully establish the moored array include:

- Ship time (~180 days) (INCOIS and CLIVAR websites will show cruise opportunities)
- Fishing vandalism (or use frequent XBTs off Sumatra/gliders?)
- Operational funding
- International coordination
- System integration (e.g. commonalities with the multi-hazard warning system)

Argo is an essential part of the observing network for CLIVAR, to obtain measurements of the variability of water mass composition. For Argo in the Indian Ocean, there is a need for:

- Shallow mixed layer resolution (barrier layers)
- Deep calibrations (below Red-Sea Water)
- Re-seeding in divergence regions.

XBT lines had been assessed and a number of high priority lines identified. The drifter array in the region lacks the required 5°x5° recommended sampling and needs full implementation in particular in terms of re-seeding of the northern (upwelling) areas.

Data management of the various elements had been reviewed with the missing element being management of the integrated dataset – a one-stop shop for research.

7.3 Atlantic Panel (C Boening)

Dr Boening noted that the focus of the Atlantic Panel has shifted from implementation to science issues with focus in turn on each of 3 science themes – the North Atlantic Oscillation, the Thermohaline Circulation (THC) and Tropical Atlantic Variability. The last panel meeting had taken place in Venice in October following a Workshop on Tropical Atlantic Variability. Dr Boening commended the panel's website at http://www.clivar.org/organization/atlantic/atlantic.php. In terms of issues related to modeling:

(i) the Atlantic Panel had a key interest in interannual variability in the Atlantic to help design observing systems. There was much interest in the status of CORE-II and planned activities. This relates to what the WGOMD does in terms of sending out information about CORE and dataset availability.

(ii) The Atlantic Panel had continued discussion of relevant metrics and datasets for WGOMD CORE runs and had produced a 2-page summary on metrics and datasets relevant to the THC. This had been expanded by Dan Wright but had so far lain fallow within WGOMD. The issue needs follow-up by WGOMD in terms of metrics needed for assessment of CORE runs. The key question is how best to develop the interaction between WGOMD and the Atlantic, and other, panels on this. Dr Boening saw the main interaction as being through CORE-II.

Action: Circulate the Atlantic Panel document to WGOMD (Action – S Griffies) and put on web page (Action – ICPO). Write to the Atlantic Panel to thank them and work with them on pointers to observational datasets (Action: S Griffies and others). Wait before taking forward with other panels at this stage beyond e.g. presentation to the Pacific Panel (S Griffies)

7.4 WCRP Climate and Cryosphere (CliC) project (A Beckmann)

Dr Beckmann summarized a number of CliC activities related to:

- Global studies with coupled ice-ocean models
- Cryospheric processes and phenomena
- Interdisciplinary science and model development

CliC is a sponsor of the Arctic Ocean Model Intercomparison Project (AOMIP – see below) and the 2nd Sea Ice Model Intercomparison Project (SIMIP2). It was also providing coordination of a set of proposed IPY activities for the Arctic to:

- determine the present environmental status of the polar regions by quantifying their spatial and temporal variability
- quantify, and understand, past and present natural and anthropogenic change in the polar regions, in order to improve predictions
- advance our understanding of polar-global teleconnections, and of the processes controlling these interactions

CliC has developed a new structure for its activities based around the so-called "CliC Project Areas (CPAs), which it is now implementing. These are:

- CPA1: The terrestrial cryosphere and hydrometeorology of cold regions
- CPA2: Glaciers, ice caps and ice sheets, and their relation to sea level
- CPA3: The marine cryosphere and its interactions with high latitude oceans and atmosphere
- CPA4: Links between the cryosphere and global climate

CPA3 and CPA4 represent areas of particular interest to CLIVAR. These cover:

CPA3: The marine cryosphere and its interactions with high latitude oceans and atmosphere
What will be the nature of changes in sea-ice distribution and mass balance in both polar regions in response to climate change and variability?

- Observational data sets and re-analyses of oceanographic and sea-ice quantities

- Reduced uncertainties regarding past variability and trends in sea-ice coverage
- Improved understanding of water mass transformation in polar regions
- Improved model predictions of future changes to sea-ice cover in both hemispheres

CPA4: Links between the cryosphere and global climate
What is the impact of changes in the cryosphere on the oceanic and atmospheric circulation? What is the likelihood of abrupt climate changes resulting from regime changes in the cryosphere?

- Improved regional and global models of high latitude climate
- Improved knowledge of cryosphere-related feedbacks to the rest of the climate system
- Understanding of the cryospheric processes that underlie global tele-connectivity in climate
- Better knowledge of abrupt climate changes associated with impacts of the cryosphere on the rest of the global climate system
- Clearer view on the role of cryosphere in global water, energy and carbon cycles

An additional set of activities under CliC are those of the Arctic Climate Panel, described in more detail below.

Dr Beckman concluded his presentation with a brief introduction to ICED which brings together climatologists, oceanographers, biogeochemists, ecosystem and fisheries scientists to generate unique Antarctic circumpolar databases and models. ICED is a natural descendant of recent global programmes with a Southern Ocean dimension:

- The Joint Global Ocean Flux Study (JGOFS), which focused on the carbon cycle;
- GLOBEC,
- The World Ocean Circulation Experiment (WOCE);
- A number of programmes of CCAMLR; and
- The completed Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) programme

It addresses three globally important questions:

- how do climate processes affect the dynamics of circumpolar ecosystems?
- how does ecosystem structure affect circumpolar ocean biogeochemical cycles?
- how should ecosystem structure and dynamics be included in the development of sustainable approaches to managing exploitation?

7.5 *The CliC (now CliC/CLIVAR) Arctic Climate Panel (M Holland)*

Dr Holland began her presentation by noting that CliC had decided in fall 2003 to create a panel (the Arctic Climate Panel, ACP) whose responsibility would be the *Arctic Ocean and its role in climate*. The panel is charged with assessing and stimulating scientific efforts to understand climate variability and predictability of the coupled land-ocean-atmosphere-cryosphere system in the Arctic, as well as the Arctic's role in the global climate system.
This includes:

- Identification of needed process studies, model experiments and reanalysis activities.
- Identification of needed sustained observations. The panel will contribute to the development of the Arctic Ocean Observing System as part of the Global Ocean Observing System and Global Climate Observing System
- Facilitating enhanced interaction between the relevant meteorological, oceanographic, cryospheric, biogeochemical and palaeoclimate communities, as well as with the Arctic scientific communities in general. In particular, it will liaise with IASC, AOSB, ISAC, ACIA, ASOF and CLIVAR's Atlantic Panel.

The focus for the panel is on synthesis of the effects of climate forcing on modes of climate variability, their impacts on Arctic regional climate and prediction and assessment of these with input to decision-making and policy. Science themes for the panel are:

Role of the Arctic as regional modifier of climate change

- Mechanisms leading to variability in cryosphere volume and extent
- Mechanisms leading to high-latitude amplifications of global climate change
- Potential for abrupt change in Arctic climate

Role of the Arctic in modifying global-scale ocean circulation and heat transport

- Mechanisms leading to variability and change in Arctic Ocean freshwater storage.
- Mechanisms leading to variability and change in Arctic Ocean energy storage.
- Exchanges with the Pacific and the Atlantic.
- Stability of the thermohaline circulation, potential for abrupt climate change. What causes the ocean circulation to change?
-

Role of Arctic in modifying global-scale atmospheric circulation

- Nature of annular modes. Are changes in the circulation of the Arctic atmosphere (and ice cover) over the last 15 years related to global warming?
- Feedbacks to greenhouse gases during Arctic change
- Energy balance: clouds, radiation
- Ozone

Role of Arctic in the global carbon cycle

- Atmospheric-ocean CO2 fluxes in a changing climate
- Methane release from melting permafrost and shallow gas hydrates
-

Predicting the future: where is the Arctic going?

- Consequences of a warmer climate.
- Consequences of a significantly different ice cover in the Arctic
- Predictability and uncertainties

Dr Holland reported that, given the panel's focus on Arctic climate variability, the ACP would be seeking endorsement as a joint CliC/CLIVAR Panel at the next meeting of the CLIVAR SSG (subsequently agreed). It was suggested that the possibility of the ACP meeting with WGOMD at its next meeting (see Section 10 below) should be explored.

7.6 The Arctic Ocean Model Intercomparison Experiment (AOMIP) (R Gerdes)

The AOMIP design currently comprises 4 basic experiments:

1. Seasonal Cycle
2. Coordinated - Spinup 1948-1978
3. Coordinated Analysis Experiment 1979-2004
4. Coordinated 100-Year Run

AOMIP's working plan for the next 2 years (June 2005 to February 2007) includes:

A. Completion of analyses of coordinated 50-year (1948-2004 – items 2+3 above) experiments:

- further intercomparison of model output
- identification of key differences
- determination of causes of differences among models
- testing of proposed model improvements
- formulation of major recommendations for model improvements

B. Formulation of coordinated 100-year model runs:

- analysis and intercomparison of model output
- investigation of Arctic Ocean and sea ice variability based on model results and observations

Key topics for AOMIP include:

- Propagation and transformation of Atlantic waters in the Arctic Ocean

- Variability of the Arctic Ocean freshwater content
- Advection schemes
- Data assimilation techniques and philosophy
- Role of tides in the Arctic Ocean and in sea-ice dynamics and thermodynamics
- Arctic climate variability in global and regional models
- General model intercomparison issues

Several scientific and modelling themes identified by AOMIP need serious attention in order to understand and to model Arctic Ocean behavior successfully. These themes are:

1. Circulation and properties of the Arctic Ocean Atlantic Water Layer (cyclonic vs. anticyclonic)
2. Variability of the freshwater content, and mechanisms of fresh water accumulation and release; uncertainties in the choices of boundary conditions for rivers, straits, and open boundaries; restoring or not restoring alternatives; and forcing data (rates of precipitation/evaporation and river runoff). All models (without restoring) have significant salinity drifts.
3. Model improvements
    a. Improvements in model numerics (advection)
    b. Improvements in model physics (tides, landfast ice)
    c. Improvements in model forcing and model validation and calibration technology.

Further details on AOMIP can be found at http://fish.cims.nyu.edu/project_aomip/overview.html. As noted above, a key issue for AOMIP is forcing. In particular there is diversity in freshwater flux forcing resulting in a lack of consistency in approach. AOMIP models are mainly regional with regional forcing. Dr Holland noted that she is carrying out AOMIP runs with a global model and is proposing to move to the Large and Yeager forcing for this, coordinating with CORE. **The group were supportive of this approach, which would help to unify the two activities (see however the discussion in Section 8 below)**.

Dr Boening noted possible close connections to CORE, the runs for which are just spinning up. AOMIP analyses could be extended to cover the CORE runs, possibly through a diagnostic sub-project of CORE-II, a concept which might be extended more widely. Though this was agreed to be a good idea, problems of access to the CORE datasets remain to be solved – it is not easy for individuals not closely connected with CORE to go to individual sites and download the needed data. WGSIP was facing similar problems and it would be useful to find out about the approach they are using.

Action – discuss issues of data management for coordinated experiments with WGSIP and consider options for CORE-II runs (S Griffies, ICPO).

In a general discussion of the issue of coordinated outputs from model runs, a request was made for streamfunction as well as Eularian velocity to be output so that the overturning circulation can be constructed. The group endorsed this suggestion but noted that for AR4 datasets this would require and extra field to be specified in the CMIP output datasets. Thus whilst the group endorsed this suggestion there would be a need to check with the WGCM Climate Simulation Panel, and through them with PCMDI, as to whether a request for an additional data field can still be submitted **(Action: S Griffies, ICPO).**

8. Interactions between WGOMD and the wider community and discussions of WGOMD focus (C Boening & S Griffies)

The key issues here were agreed to surround how best to progress CORE-II, including the number of groups engaging in this activity and how wide the invitation for others to participate in diagnostic projects can be made. Prof. Willebrand suggested that two key issues are to identify the key science questions and to determine and action how to make the data from the runs available (see above). This may need a workshop to discuss how to take the CORE runs forward.

Dr Griffies reminded the group that the present strategy is to complete the paper in Ocean Science first, based on the runs for 5-6 models, before broadening participation in CORE activities. This should clarify a lot of the issues. This led to further discussion of the protocols for CORE runs.

Dr Drange stated that he would like to see a protocol that would lead to a realistic ocean climate on average, to which the variability would be added. There is an issue as to whether the salinity relaxation applied in CORE-I would also be applied for CORE-II runs.

In this context, the issue of whether or not to apply under-ice relaxation (Section 6.1) was again raised. Dr Gerdes couldn't see why this shouldn't be done. Prof. Willebrand noted that it leads to decoupling of ice. Dr Boening suggested using a restoring on a timescale of a year or so. Prof. Willebrand asked where the focus of CORE runs was – on ice as such or the global ocean? If the latter then one could be more practical with respect to the formulation of the forcing for sea ice. However where the focus is on the Arctic (as would be the case if CORE runs were to contribute to the aims of AOMIP) then more care would be needed. If AOMIP were indeed to be involved then it would be best to have a unified approach. Asked if there was any consensus in the Arctic community as to the best approach, Dr Gerdes noted that in terms of AOMIP, there are aspects of the Large and Yeager forcing that AOMIP may not buy into. The topic could be discussed at the next AOMIP meeting the weekend before the Hawaii Ocean Sciences conference (20-24 February 2006).

Dr Banks raised the issue of just what the protocol should be for CORE-II in the light of these discussions. Overall it was felt that options should be left open but ensuring a weak restoration only. Otherwise one was on the edge of having a highly specified MIP rather than a reference experiment. Groups should in any case, store relevant fields as part of model diagnostics.

In conclusion, and returning to the issue of how WGOMD should be seeking to link to the wider community in respect of CORE runs, Dr Boening stated that felt that the philosophical difference between CORE-I and CORE-II should be kept in mind. CORE-I outputs would mainly be of interest to modeling groups. CORE-II on the other hand had much wider science applications and so of much wider interest. This needs to be considered in terms of involvement of the wider community in analysis of CORE runs.

Dr Cattle noted the relative lack of information on CORE and other activities (e.g. AOMIP) on the WGOMD website. The members of the group were requested to examine what was on the WGOMD pages and send additional material to Dr Cattle **(Action: All)**. Dr Griffies and Dr Cattle would consider, in particular what additional material was required to give a fuller description of CORE activities overall. **(Action: S Griffies, ICPO)**.

9. WGOMD membership

It was noted that the terms of four members of the group would expire at the end of 2005. Dr Boening (as co-chair), Dr Chassignet, Dr Hasumi and Dr Treguier. The group thanked Dr Boening for his work as co-chair which they were highly appreciative of and expressed the hope that he would be willing to continue for a further two years as an ordinary member of the group. Dr Chassignet indicated his willingness to continue as a member of the group for a further two years also whilst Dr Hasumi suggested a potential Japanese replacement for his position. The chair would discuss this, a potential replacement for Dr Treguier and the two proposed renewals with the CLIVAR SSG. **(Action: S Griffies, ICPO).**

10. Date and place of next meeting

Dr Drange informed the group of the planned Open Science Conference on "Polar Dynamics: Monitoring, Understanding and Prediction" to be held from 29-31 August 2007 in Bergen, Norway (see http://www.igsoc.org/symposia/Bergen_2007.pdf). He proposed that the next meeting of the group should take place in association with this, with the group meeting over the weekend before, on the 27 and 28 August 2007. He could make an early hotel block booking if the group agreed. **(Action: H Drange)**. In discussion, it was suggested that the group seek to meet alongside and in collaboration with the CliC (now CliC/CLIVAR) Arctic Climate Panel, with a joint half-day session included. Dr Holland undertook to discuss this with the ACP **(Action: Dr Holland)**. The group decided to go ahead with plans for the meeting on this basis, and thanked Dr Drange for his proposal. If plans worked out. the Arctic focus this would give would complement the Southern Ocean focus of the present meeting nicely and help to strengthen links with both ACP and AOMIP.

11. Closure of the meeting

In drawing the meeting to a close, Dr Griffies and the group once again expressed their thanks to Dr Boening for his work as co-chair. They also expressed their sincere thanks to CSIRO Marine and Atmospheric Research for their generous hospitality in hosting both the meeting and the workshop, which had accompanied it. Finally Dr Griffies requested attendees submit a short account of their presentations to him to help in drawing up the report. **(Action: all)**

Annex A

WGOMD-6 meeting

CSIRO Division of Marine & Atmospheric Research, Hobart, Australia
8 & 11 November 2005

List of attendees

S. Griffies (chair) Geophysical Fluid Dynamics Lab., NOAA, Princeton, USA

C. Boening IFM-GEOMAR, Kiel, Germany

H. Banks Hadley Centre, Met Office, Exeter UK

E. Chassignet RSMAS, Miami, USA

H. Drange University of Bergen, Norway

M. England University of New South Wales, Australia

H. Hasumi Center for Climate System Research, Tokyo, Japan

M. Holland National Center for Atmospheric Research, Boulder, USA

A.-M.Treguier IFREMER, Brest, France

R. Gerdes (CliC rep.) Alfred Wegener Institut für Polar- und Meeresforschung, Bremerhaven, Germany

A Beckman, Finland

S Rintoul CSIRO Division for Marine & Atmospheric Research, Hobart, Australia

S O'Farrell, Australia

T McDougall, Director, CSIRO Division for Marine & Atmospheric Research, Hobart, Australia

J Willebrand, IFM, Kiel, Germany

D Webb, National Oceanography Centre, Southampton, UK

S Wijffels, CSIRO Division for Marine & Atmospheric Research, Hobart, Australia

H Cattle, ICPO, National Oceanography Centre, Southampton, UK

Annex B

WGOMD-6 meeting

CSIRO Division of Marine & Atmospheric Research, Hobart, Australia

8 & 11 November 2005

Draft Agenda

Tuesday, Nov 8

1. Welcome

2. Report from Clivar SSG (Cattle)

3. Report from WGCM (Cattle)

4. Reports from WGOMD committee members on modelling activities in their sector

5. CORE-I (ocean-ice simulations with repeating annual cycle); manuscript presentation (Griffies and Boening)

6. Simulations with interannual Large and Yeager forcing and a discussion of the dataset issues, etc: NCAR experiences (Holland); Kiel experiences (Boening)

7. CORE-III: thermohaline perturbation experiments (Gerdes)

8. Discussion of metrics to gauge the fidelity of CORE simulations

Friday, Nov 11

9. Wrap-up from Southern Ocean Modelling workshop

10. Reports from other panels and committees: Pacific (Hasumi); Atlantic (Boening); Southern (Rintoul); Indian (Wijffels); AOMIP (Gerdes); CliC (Beckmann)

11. Interactions between WGOMD and CLIVAR Panels (Boening)

12. Discussions of WGOMD focus for next years (Boening and Griffies)

13. Proposal for the next meeting of WGOMD

14. Summary of action items

Annex C

Reports from WGOMD committee members on modelling activities in their sector

C.1. Modeling activities for IPCC AR4 in Japan (H Hasumi)

Three groups have participated in IPCC AR4 future climate projections from Japan. The groups are: - Central Research Institute for Electric Power Industry (CRIEPI) - Meteorological Research Institute of Japan Meteorological Agency (MRI) – A consortium made up of the Center for Climate System Research, the National Institute for Environmental Studies, and the Frontier Research Center for Global Change (CCSR/NIES/FRCGC) CRIEPI is collaborating with NCAR and LANL, and their model is the NCAR CCSM. Since their data submission is made under the name of NCAR/LANL, its description is skipped here. The model used by MRI is MRI-CGCM, which is based on the AGCM and OGCM developed at MRI. Their model resolution is T42 for the atmosphere and 2.5 deg (lon) x 0.5-2.0 deg (lat) deg. for the ocean. Their principal contribution to IPCC AR4 is assessment of regional impacts (tropical cyclones, torrential rainfall, floods, ...) based on time slice experiments using CGCM-projected SST and a very high resolution AGCM (20 km horizontal resolution). The model used by CCSR/NIES/FRCGC is called MIROC, which is based on CCSR/NIES AGCM and COCO (CCSR Ocean Component Model). Two models of different resolution are used: T106 atmosphere and ¼ deg (lon) x 1/6 deg (lat) deg. ocean for MIROC-high resolution, and T42 atmosphere and 1.4 deg (lon) x 0.5-1.4 deg (lat). ocean for MIROC-medium resolution. One of their principal contributions to IPCC AR4 resides in the use of an eddy-permitting ocean model. Although global features of climate change (globally averaged surface temperature rise, globally averaged sea level rise, THC weakening, ...) are similar between MIROC-high resolution and MIROC-medium resolution, a high resolution ocean model gives much more confident projections for oceanic narrow, swift currents, which have significant impacts on climate changes of regional/basin scales. It is exemplified in their analyses on the impact of an accelerated Kuroshio on North Pacific mid-latitude sea surface temperature (SST), and on the spatial pattern of sea level rise.

C2. Ocean modeling activities at the Frontier Research Center for Global Change, Japan (H Hasumi)

The Frontier Research Center for Global Change (FRCGC) is one of the seven research centers owned by Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Climate modeling is the central mission of FRCGC. It is made up of six "research programs", each of which has about 20 researchers, and three of them have ocean modeling groups. Several different ocean models are used by these groups. The Climate Variations Research Program targets tropical air-sea coupled phenomena (ENSO, Indian Ocean Dipole Mode, ...) and on Kuroshio forecasting, and they use OFES (MOM3 tuned for the Earth Simulator), POM, and OPA. The Global Warming Research Program is focused on IPCC/CMIP type coupled modeling, in collaboration with CCSR and NIES. The ocean model used in this group is COCO. The Global Environment Modeling Research Program has two different groups doing ocean modeling. Its Next-Generation Model Development Group is tasked with eddy-resolving ocean modeling and development of a cubic grid OGCM. Their eddy-resolving ocean modeling is currently performed using COCO. Development of their own cubic grid OGCM is close to completion and will be used in their eddy-resolving ocean modeling soon. The Ocean Data Assimilation Research Group is tasked with development of a 4D-VAR coupled data assimilation system, and the ocean model used in this group is OFES.

C3: Report on ocean model activities at GFDL, USA, Jun 2004-Nov 2005 (S Griffies).

There are two broad categories of activities that have been the focus of GFDL ocean scientists: (1) work in support of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) on climate change, (2) developments of physical parameterizations and numerical methods. The remainder of this report summarizes these activities.

i) IPCC activities

The development of the GFDL coupled climate model in support of AR4 was completed in the summer of 2004. Scenario experiments were submitted to the PCMDI repository. The ocean component of the coupled model has been described to WGOMD in the past: it has roughly a 1 degree ocean using the mom4p0 code, with 50 levels and 1/3 degree at equator. Numerous studies are now being conducted to document the model's design and simulation characteristics. It will take years to fully evaluate the model simulations.

ii) MOM4 past and future

--There have been four sub-releases of MOM4.0 since January 2004. There are roughly 300 registered users from 30 countries using 35 computational platforms. They represent about 1200 scientists, engineers, and programmers using the code and simulation results for research and development.

--The main applications of MOM4 include (1) IPCC global climate change modelling, (2) Earth system modelling with interactive land, atmosphere, ocean biogeochemistry and ecosystems, (3) Global and regional process studies such as for paleo-oceanography, idealized climate change simulations, thermohaline shutdown, and physical process studies.

--The next release of MOM4, planned for September 2006, will be MOM4.1. This code which will include rudimentary features of general vertical coordinates, such as zstar, pressure, and sigma.

iii) Climate Process Teams

GFDL and Princeton University scientists have been leaders in the Climate Process Teams (CPT) that have focused many US scientists on limitations of physical parameterizations used in the global ocean climate models. The two projects funded in this area focus on (A) gravity current and entrainment processes, which are key to setting properties of deep water masses throughout the World Ocean, (B) interactions between mesoscale eddies and the nonhydrostatic boundary layers in the upper and lower ocean. In their two years of existence, work from these two teams have resulted in improved parameterizations of direct use for ocean climate models. It is anticipated that further developments will come online within the next two years, thus providing a more firm physical and numerical basis for future ocean climate models.

iv) Evolution of GFDL ocean codes

There are three main model developers at GFDL: Alistair Adcroft, Stephen Griffies, and Robert Hallberg. These developers respond to the needs of evolving scientific interests. Examples of these interests include (1) Refined resolution climate models, (2) Biogeochemistry and ecosystem applications, (3) Earth system modeling, (4) Coastal impacts of climate change, (5) Non-hydrostatic processes at very refined resolutions. They also aim to include state-of-the-science physical parameterizations (e.g., mixed layers, mesoscale eddies), algorithm fundamentals (e.g., time stepping, vertical coordinates), better understanding of the ocean (e.g., equation formulations), and computational efficiency and platform portability. Input is provided by others in the GFDL/Princeton community, as well as many collaborators and the international user communities for the Hallberg Isopycnal Model (HIM), the MITgcm, and MOM4.

Given the strong set of intellectual and computational resources at GFDL, it has been decided to merge the efforts of Adcroft, Griffies, and Hallberg over the course of the next 3-5 years to produce a GFDL unified ocean model code. This effort aims to bring together diverse understandings of the ocean and how to simulate a wide range of scales. Various algorithms will be investigated, with code evolutions involving suites of applications to test methods and flesh out favourable approaches. This effort is a major research and development project, presently in its early stages at GFDL. Much research remains to determine particulars of algorithms. Notably, unification does not squelch diversity within this vision. Instead, it facilitates scientific interactions, reduces technical barriers, and enhances the robustness of the science and engineering going into the model codes.

Given the strong interests in the US and international communities for more readily avaialble, thoroughly documented, and fundamentally flexible model designs, the unified GFDL code may provide a useful step towards more widely supported and utilized ocean codes.

C4. Ocean modeling activities in the UK (H Banks)

1. National Centre for Ocean Forecasting

The National Centre for Ocean Forecasting (NCOF) was formally opened in March 2005. NCOF aims to assist coordination of UK ocean forecasting activities. NCOF has been established by the Met Office in association with NERC science labs: PML, POL, SOC, ESSC. The aim of NCOF is to establish ocean forecasting as part of the national infrastructure. It includes development of deep ocean, shelf seas, storm surge and surface wave forecasting.

2. Status of UK coupled modelling

The most recent coupled model developed at the Hadley Centre is HadGEM1 (Johns et al., 2005; McLaren et al., 2005). HadGEM1 runs for IPCC are now included in the database at PCMDI. Relative to HadCM3 (Gordon et al., 2000), the key features of HadGEM1 are:

- Increased horizontal resolution: 1° up to 1/3° on Equator
- Increased vertical resolution in ocean (40 vertical levels)
- Linear free surface with explicit freshwater fluxes (rather than rigid lid)
- Fourth order advection scheme with upwind at the ocean bottom to improve stability (rather than centred differencing)

The Hadley Centre and NERC centres are collaborating on the development of UK-HiGEM, a high-resolution version of HadGEM1. The resolution of the HiGEM model is 1° atmosphere and 1/3° global ocean. Initial results from HiGEM suggest that high resolution can reduce the cold surface temperature bias in the Equatorial Pacific seen in HadGEM1. In parallel with HiGEM, the UK (Hadley Centre and NERC centres) are collaborating with Japan on the UK-Japan Climate Collaboration. This is a three year project to develop a model incorporating a full range of climate-chemistry-ecosystem interactions at the highest resolution possible.

The CHIME (Coupled Hadley-Isopycnic Model Experiment) model was derived from HadCM3 by replacing the ocean component with a new model. It therefore forms part of a traceable hierarchy with the Hadley Centre models. The new ocean (HYCOM) uses hybrid-coordinates in the vertical. This may give differences in the way in which water masses are represented and in the evolution of the modelled climate system - compared to most other climate models which use fixed levels in the vertical. This offers a real alternative to the UK climate modelling community. A 120 year control run has been performed and a new clean control is about to be undertaken.

3. New ocean models

The Nucleus for European modelling of the Ocean (NEMO) is based on French OPA model. The Met Office is working on transition of all ocean modelling activities to use NEMO (deep ocean forecasting, shelf sea modelling, seasonal and climate forecasting). The Met Office plans to run pre-operational versions of the FOAM ocean forecasting system using NEMO, to establish a climate version of NEMO that is at least as good as the ocean component of HadGEM1 and to explore the potential of NEMO for shelf seas modelling.

The Imperial College Ocean Model (ICOM) is a next-generation unstructured mesh ocean model. An adaptive mesh would allow a wide range of critical spatial and temporal scales to be resolved. In particular, to model the ocean's role in the Earth system and climate, there is a need to resolve boundary currents, eddies, overflows, convection and to include shelf seas. The development of the model is being led by Imperial College in collaboration with the Department of Meteorology, Reading University and National Oceanography Centre, Southampton.

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C5. Australian ocean modelling activities (M England)

Background

Australian ocean model development (OMD) up until 2004 was focused on four main activities: (i) Development of the oceanic component of the CSIRO coupled climate model (Mk 3) based on the GFDL MOM version 2.2, (ii) Development of the oceanic components of the BMRC coupled climate model and the BMRC POAMA model (also based on the GFDL MOM) (iii) Development of various regional ocean models, and (iv) several University-lead initiatives in OMD (e.g., TPAC 1/8 degree Southern Ocean sector model, the UNSW "off-line" ¼ degree global tracer model, and so on).

Strategic developments and new funding streams over the past few years has lead to a consolidation of these activities into the following:- (1) Development of the AusCOM ocean model that will form the ocean-ice component of a single IPCC-class Australian global climate system model known as "ACCESS". ACCESS will be developed jointly by CSIRO and BMRC, with contributions from Australian Universities. Funding for an ARC Network in Earth Systems Science, with a strong modelling focus, will support the University sector contribution to ACCESS-AusCOM development. (2) Large investment by the Royal Australian Navy (RAN) to support the development of a capacity for accurate ocean modelling of Australia's Exclusive Economic Zone (EEZ). Other smaller-scale projects in OMD will continue within both the University and block-funded research agencies (CSIRO, BMRC), however much effort will be invested into activities (1)-(2) above.

Australian OMD post-2005

Future Australian ocean model development will be focussed on two primary activities:- (1) AusCOM (the ocean-ice component of the next Australian IPCC-class global climate system model "ACCESS"), and (2) BlueLINK (the RAN sponsored model prediction system for Australian regional oceans) and the related Relocatable Ocean-Atmosphere Model (ROAMS).

The Australian Community Ocean Model (AusCOM)

AusCOM is a collaboration between the Antarctic Climate and Ecosystems CRC, the ARC ESS Research Network the Australian Antarctic Division, BMRC, CSIRO Marine and Atmospheric Research, TPAC, and several Australian Universities. The ocean model employs the MOM4 (p0d) code, generalised horizontal coordinates on an Arakawa B-Grid, nominal 1° x 1° grid with latitudinal refinement to 1/3° near the Equator, and isotropic in the Southern Ocean to 60°S. It uses a bipolar grid, with the North Pole relocated into Siberia (Roberts et al., Ocean Modelling, in press). The model is Z level (46 vertical levels 0 – 5050 m, resolution 5 m – 250 m). The baroclinic velocity and tracers evolved in time using a predictor-corrector scheme. The model includes standard features built into MOM4, such as an explicit non-linear free surface, variable depth bottom cells, the McDougall (2003) equation of state, Griffies et al. (1998) neutral tracer diffusion, and the Griffies (1998) implementation of Gent and McWilliams (1990). The AusCOM model also includes several extensions to MOM4 (ACOM2 solar penetration, a Chen et al. mixed layer scheme, and the Wilson (2000) Richardson number dependent vertical mixing. The AusCOM sea-ice model is a Hibler-type dynamic-thermodynamic model including calculations of ice dynamics, ice thickness redistribution, ice advection, ice thermodynamics, and a complete radiation budget.

BLUElink: Ocean Forecasting for the Australian EEZ

A partnership between Australia's Bureau of Meteorology, CSIRO MAR and RAN. The ocean model is known as the "Ocean Forecasting Australia Model" (OFAM), which comprises a global configuration of MOM 4.0 with 0.1° resolution around Australia and 47 vertical levels (35 in the upper 1000-m). The

Bluelink Ocean Data Assimilation System (BODAS) adopts Ensemble Optimal Interpolation using a 72-member ensemble of model anomalies. Two model activities thus far include (i) the Bluelink ReANalysis (BRAN): a 1992-present reanalysis that assimilates sea-level from altimeter and coastal tide gauges; as well as *in situ* temperature and salinity; and (ii) the Operational Forecast System: run at the Bureau of Meteorology, with a minimum of 2 forecasts per week.

Ocean Forecasting Australia Model, OFAM.
The aim of OFAM is to resolve the mesoscale ocean variability around Australia. The model employs MOM 4.0 with a polar grid, 0.1 degree resolution around Australia (coarser elsewhere; e.g., 2 degrees in the North Atlantic), 47 geopotential levels (35 in the upper 1000m), vertical mixing after Chen et al. (1994) and a hybrid bulk and Richardson-dependent scheme, horizontal friction using the Smagorinsky scheme described by Griffies and Hallberg (2000), isopycnal mixing and GM, the Sweby scheme for advection and MOM4.0c time stepping.

Relocatable Ocean-Atmosphere Model (ROAM).
ROAM presently employs a "home-grown" ocean model (developed by Mark Holzer) applicable to coastal applications, including the use of sigma coordinates. Proposed developments for ROAM over the next 5 years include the following (i) Inclusion of surface waves; (ii) Data assimilation (particularly of real-time XBT data from on-location deployment by RAN); (iii) Replacement of the ocean model with a coastally-enhanced version of MOM (the challenges in this regard include the need for terrain-following coordinates, resolution of tides, an appropriate BBL scheme, 2-way nesting, and a better vertical mixing scheme), (iv) Enhanced air-sea coupling (2-way heat fluxes, influence of waves); and (v) release of a freely-available research version (with non-automated boundary conditions and external parameter specification).

C6 Ocean Modelling activities in Canada (submitted manuscript) (R Greatbatch)

Acronyms:
MSC Meteorological Service of Canada
DFO Department of Fisheries and Oceans
BIO Bedford Institute of Oceanography
IOS Institute for Ocean Sciences
DND Department of National Defense
RMC Royal Military College, Kingston, Ontario

Moving from east to west:

1. Entcho Demirov. Memorial University of Newfoundland.
A NSERC funded project "High resolution modeling of the Labrador Sea: Variability, processes of deep convection and interaction with the global ocean" is under development in the Department of Physics and Physical Oceanography at Memorial University of Newfoundland. The project aims to develop a high resolution ocean model and data assimilation scheme for use in studying coupled sea-ice variability of the Labrador Sea. The model is MITgcm and in its final version is supposed to have a horizontal resolution of about 3 kilometers. The data assimilation scheme that will be implemented within the model is a reduced-order extended Kalman filter (SEEK). The model will be used in a study of the Labrador Sea variability during the 1980s and the 1990s.

2. Charles Hannah (BIO/DFO)
A major new initiative at BIO is a national interagency collaboration to pursue the development and application of the OPA model for two purposes: 1) creation of a Canadian global coupled ocean-atmosphere-sea ice coupled system and 2) enhanced regional operational oceanography systems. At BIO (Lu, Wright, Brickman, Chassé, Hannah) there will be activities related to the extension of data assimilation capabilities, examination of the influence of improved representation of "choke points" on large scale dynamics, modelling the decadal scale variations, and coupled Arctic-North Atlantic modeling. Work on the POP model is continuing with the development of the "spectral nudging" method for assimilation of observed hydrography climatology (Wright et al. 2005), the assimilation of satellite altimetry using the Cooper-Haines (CH) methodology and a study of the decadal variability in the sub-polar North Atlantic using a coarse (1 degree) spatial resolution grid. The development of the ice-forecast system based on POM (Yao et al., 2000;

Dunlap and Tang, 2005) continues with recent domain extensions so that the model now extends from Baffin Bay in the north to Cape Cod in the south. Current development activities include an improved representation of the near-surface dynamics and investigation of physical controls on plankton abundances. In the Gulf of St. Lawrence the development of a biophysical modeling system based on HANSOM continues (Chassé 2002, 2003). New work involves adding a ice model, dynamical downscaling of climate change scenarios to investigate potential impacts on larval fish, and a 200 m resolution application to Northumberland Strait. Work with the finite element models continues in the nearshore and coastal zone with an emphasis on including intertidal areas on the Bay of Fundy (Dupont et al. 2005; Greenberg et al. 2005) and recent work on modelling the paleotides using reconstructed bathymetries.

3. Keith Thompson (Dalhousie University) and Dan Wright (BIO/DFO)

POP activities (collaboration between DFO(BIO), Dalhousie and RMC)

1) Development of the “spectral nudging” method for assimilation of observed hydrography climatology. The method maintains the model climatology consistent with the observed climatology while permitting higher frequency and smaller scale variability to evolve according to the model dynamics.
2) Assimilating along track satellite altimetry and Argo TS profiles into POP using a blended form of Cooper-Haines and multivariate optimal interpolation.
3) Assimilation of mean sea surface topography (based on GRACE gravity data).
4) Assimilation of Lagrangian data from Argo floats.
5) A modeling study of the decadal variability in the sub-polar North Atlantic using a coarse (1 degree) spatial resolution of the North Atlantic.

NEMO (OPA) activities at DFO and planned future collaborations with Dalhousie, MSC and others

Researchers at DFO Labs are presently implementing and testing OPA on local machines. Future work will include:

1) Extension of data assimilation capabilities
2) Establishment of a global coupled ocean-atmosphere-sea ice coupled system in an interagency collaboration involving MSC, DFO, DND and university researchers.
3) Establishment of enhanced regional operational oceanography systems.
4) Examination of the influence of improved representation of “choke points” on large scale dynamics
5) Modelling and analysis of decadal scale variations in water mass properties
6) Arctic and coupled Arctic-NA modeling.

4. Richard Greatbatch and Jinyu Sheng (Dalhousie University)

We run a number of mostly z-coordinate models (CANDIE, FLAME and, recently, MOM4) over a range of time and space scales from a data assimilative model of Lunenburg Bay, Nova Scotia (based on CANDIE) to the North Atlantic (CANDIE and FLAME) and the global ocean (MOM4). In addition, the POM (sigma-coordinate) model is being applied to the Scotian Shelf. The Lunenburg Bay model is being coupled to a bio-geochemical model, and the larger scale models are being used to study the role of eddies and the global climate problem. A novel feature of our work (in collaboration with colleagues at IfM-GEOMAR) has been the development and application of the “semi-prognostic method” (SPM), an adiabatic assimilation technique that can be used to correct a model for systematic bias (e,g, in the Gulf Stream and “northwest corner” regions). The SPM has been successfully applied to models of both non-eddy-permitting and eddy-permitting resolution. Since the method is adiabatic, it is ideal for tracer studies and has been used to study the uptake and spreading of CFCs in the North Atlantic, and the carbon cycle (the latter by colleagues at IfM-GEOMAR). The SPM can also be used both as a data assimilation technique, and as a diagnostic tool, a recent application being to probe the role of eddies in driving the Gulf Stream recirculation gyres and the “northwest corner” region (east of Newfoundland).

5. Francois Saucier (l’Université du Quebec ‡ Rimouski/DFO)

Regional sea ice – ocean – atmosphere modeling for the inland seas of Canada

Prognostic eddy permitting sea ice – ocean models are being developed for the Gulf of St. Lawrence (Saucier et al., 2003) and Hudson Bay (Saucier et al., 2004). These models are flux-coupled to the Canadian weather forecast model GEM (Pellerin et al., 2004), and to the Canadian Regional Climate Model (Qian et al., 2005). Decadal-long hindcast solutions are compared with various observations and demonstrate skillful predictability of tidal to interannual sea ice and ocean conditions (e.g., Smith et al., 2005a, 2005b). The models are being applied operationally at Fisheries and Oceans Canada, at the Canadian Meteorological

Centre, at the Ouranos Consortium for Climate Change, and to drive various ecosystem and biogeochemical models (e.g., Le Fouest et al., 2005). Another modeling activity focuses on applying the dynamical core of the Mesoscale Community Model MC2 from A. Robert to the ocean (Roy et al., 2005).

6. Frederic Dupont (l'Université Laval, Quebec)
This work is an continuation of the work started at the Bedford Institute of Oceanography on modelling of the Canadian Arctic Archipelago by Nicolai Kliem and David Greenberg using an unstructured finite-volume numerical model (Chen et al., 2003). The objectives are to quantifying the exchange in heat and freshwater between the Arctic Ocean and the North Atlantic, the effect of tidal mixing and precisely locating the major passages that are of high scientific interest to the climate community. The complexity of the region makes the unstructured grid approach very natural. One important modification to the original code is the addition of a generalized vertical coordinate which allows for horizontal levels (and isopycnal as well) as opposed to the original sigma coordinate which is commonly used in the coastal community. This vertical (or hybrid) coordinate allows for resolving tidal mixing in the bottom layer and for a better conservation of the stratification during long term integrations (more than several years). Because of the very strong sea-ice cover the ocean model has been coupled to a triangular finite element ice model based on the Hibler viscous-plastic rheology and full thermodynamics. This may lead to the development of a Canadian oceanographic forecasting capabilities for the Arctic Archipelago sea-ice cover and currents. Future plans include coupling the physical model to a simple ecosystem model developed at Quebec-Ocean that includes phytoplankton and zooplankton and to a fish larval development model.

7. David Straub (McGill University)
We are using relatively simple models (e.g., QG and/or triply periodic Boussinesq or Hydrostatic equations) to explore various issues relating to the energetics of ocean circulation, multiple (statistical) equilibria in high Reynolds number gyre simulations and ACC transport.

8. Mike Stacey (RMC)
Inlet Modelling
Two-dimensional (i.e, laterally-averaged) models of inlets have been used to study the influence of the tides, the winds and fresh-water runnoff on the circulation of the inlets/fjords. These studies include examinations of the partition of tidal energy and the subsequent rate of mixing in the inlets, and the influence of breaking waves on the near-surface circulation. Examples of inlets that have been studied are Knight Inlet, Burrard Inlet/Indian Arm, and the Saguenay Fjord.

North Pacific Modelling
The Parallel Ocean Program (POP) is being used to simulate the circulation of the North Pacific Ocean, with particular emphasis on the Northeast Pacific Ocean. The eddy dynamics of the circulation along the coasts of British Columbia and Alaska is being studied. Spectral nudging is used in the POP in order to hold its mean T and S climatology close to that of the observed climatology. The model has been validated by comparing the simulated sea-surface height statistics to those obtained from satellite altimetry observations. The long trem goal is to develop a nowcast/forecast capability for the Northeast Pacific.

9. Kevin Lamb, Francis Poulin and Marek Stashna (University of Waterloo)
Activities are focused on small scales, including modelling the generation of internal waves by tidal currents and by steady flows over topography, shoaling and breaking internal solitary waves, interaction of internal waves with the bottom boundary layer and instability of time-dependent shear flows.

10. Paul Myers (University of Alberta)
Modelling is focussed on the Labrador Sea and the sub-polar North Atlantic, although the domain is presently being extended in some cases to include all of Baffin Bay, the Nordic Seas and more of the North Atlantic. The majority of this modelling is being carried out with the ocean only SPOM model, but a start is also being made on using the ice-ocean OPA model, based upon the NATL4 configuration used at Brest in France. Work over the past year has focussed on the drift in freshwater in the Labrador Sea, impact of the export of freshwater from the Canadian Arctic and how freshwater is exchanged from the boundary currents to the interior. Diagnostic calculations using the same model are also being carried out to help understand changes in the observed circulation in the region. Finally, a few simple paleoceanographic experiments have been conducted.

11. University of British Columbia (Andy Ridgwell):
Development and application of a representation of marine carbon cycling within a reduced physics (frictional geostrophic) 3D ocean model is being carried out as part of the 'GENIE-1' Earth system model (also including 2D energy-moisture balance model (EMBM) of the atmosphere and dynamic-thermodynamic sea-ice). Calibration of the modern marine carbon cycle within the ocean GCM is described in Ridgwell et al. "Ocean geochemical data assimilation within an Earth System Model" [submitted] (www.seao2.org/publications.html). Work applying this model in eludicating future anthropogenic impacts on calcification in the open ocean and fossil fuel CO_2 uptake by the ocean is on-going (manuscript "Ensemble analysis of marine 'CO_2-calcification' feedback and fossil fuel CO_2 uptake" in preparation). Application of the ocean model includes feedbacks between CO_2 and climate; e.g., associated with stratification and changes in the strength of the Atlantic meridional overturning circulation. Also, the geochemical interaction between ocean carbon cycling and deep-sea sediments is being studied (manuscript "Deep-sea sediment data assimilation within an Earth system model: The role of carbonate dissolution in sequestering fossil fuel CO_2" in preparation).

William Hsieh:
Improving hybrid coupled models (HCM) of the tropical Pacific by the use of neural network (NN) methods for nonlinear regression has been pursued. NN was introduced for the nonlinear parametrization of the subsurface temperature in the Lamont (Zebiak-Cane) ocean model, and for the nonlinear estimation of the wind stress anomalies from the sea surface temperature anomalies (SSTA). For comparison, corresponding linear regression (LR) models were also built. By combining the NN or the LR version of the ocean model and the atmospheric model, four HCMs resulted. All the coupled models (including the original Lamont coupled model) were too linear compared to the observations. However, using NN in the ocean model and in the atmospheric model alleviated the weak nonlinearity in the coupled models (Li et al. 2005).

Grant Ingram:
Q. Wang (graduate student)is using MIT GCM ice-ocean coupled model to study upwelling in the southern Beaufort Sea. W. Williams (PDF)is using ROMS model to look at upwelling at Cape Bathurst in Canadian Arctic coastal waters and may explore canyons on Mackenzie Shelf using a model developed by Hyun and Klinck.

Susan Allen:
Using the MIT-GCM we have been investigating stratified flow over submarine canyons. We have been comparing results from the model to laboratory experiments to test the numerical algorithms. Results from the MIT-GCM, a z-level model, are also being compared to results from models using a vertical coordinate that is terrain-following.

We have developed a one-dimensional model of the Strait of Georgia based on KPP mixing dynamics and parameterized estuarine circulation. The model has been coupled to a simple biological model and the coupled model correctly predicts the interannual variation in the timing of spring bloom.

12. Rick Thomson (IOS)
IOS has an ongoing project which involves the development of an operational ocean model for the northeast Pacific and adjacent coastal waters based on the Princeton Ocean Model (POM). Model development is being conducted at the Institute of Ocean Sciences (Department of Fisheries and Oceans) as part of continuing research programs with (1) Defence Research Development Canada (DRDC) to monitor current and water property variability in the northeast Pacific, (2) the US National Oceanic and Atmospheric Administration (NOAA) ECOHAB-PNW to investigate harmful algal blooms in the shelf waters off Vancouver Island and Washington State, and (3) the BC Provincial Government Climate Change Section plan for storm surge warning capability for the coastal waters of British Columbia. They use US Navy COAMPS winds at 1/4 degree for both the 1/8 degree (12 km) POM model of the NE Pacific and the 1/24 degree (4 km) model for the BC coast. They also are currently archiving 12 km and 4 km resolution gridded wind fields from the University of Washington MM5 operational model. These are being provided from UW to help with model simulations for the ECOHAB study, and are not currently used in IOS's operational modelling.

The goal of this project is to provide up to 48-hour forecasts of ocean conditions (temperature, salinity, velocity and sound speed) for the open northeast Pacific Ocean and storm surge elevation conditions for the coastal waters of southwest British Columbia which are updated once per day and made available in real time for operational purposes. For the offshore region, daily 48-hour forecasts from an operational 1/8 degree POM model are presently being made available via an FTP site. These model forecasts utilize nowcasts of temperature and salinity provided by the U.S. Naval Research Laboratory through the MODAS (Modular Ocean Data Assimilation System) system and atmospheric forecasts based on the U.S. Navy COAMPS (Coupled Ocean-Atmosphere Mesoscale Prediction System) model. The most critical characteristic of the wind fields is accessibility to high resolution winds for the coastal areas.

13. Bill Merryfield (Canadian Centre for Climate Modelling and Analysis/MSC)
The CCCma ocean model is a primitive equation, z-coordinate global model that has been upgraded to incorporate versions of the tidal mixing parameterization of Simmons et al. (2004), the anisotropic viscosity parameterization of Large et al. (JPO 2001), and a modified version of the KPP diapycnal mixing parameterization that produces more realistic wind-driven mixed-layer depths. Resolution has been increased to
1.41 deg (lon) x 0.94 deg (lat), with 15 m vertical resolution in the upper ocean. Recent applications include use in developmental versions of the CCCma coupled climate and Canadian ocean carbon cycle models, and model-based investigations of the influence of tidal mixing on global circulation (Saenko and Merryfield JPO 2005) and of ocean heat transport (Saenko and Merryfield GRL submitted).

14. Andrew Weaver (University of Victoria)
Andrew makes extensive use of a MOM model coupled to an energy moisture balance model for climate and paleoclimate studies.

15. Youmin Tang (University of Northern British Columbia)
Using the OPA8.1 OGCM, we are extending our 3D-Var assimilation system (Tang et al. 2004) from a Pacific Ocean to a global oceanic domain for the assimilation of sea surface observations (i.e, sea surface temperature and altimetry data). We are also using an OPA based hybrid coupled model (a statistical atmospheric model coupled to OPA8.1) to investigate ENSO predictability for a long period 1860-2004. A 6-layer dynamical oceanic model (Tang 2002) has also been used to study the data assimilation and ENSO predictability, and provides real-time ENSO prediction as well.

C7 Ocean general circulation model development in Norway, 2005 (H Drange, M Bentsen, P W Budgell and Lars Petter Roed)

The main groups working with OGCM development in Norway are located in Bergen and in Oslo. All climate- related research in Bergen is organized under the Bjerknes Centre for Climate Research (http://www.bjerknes.uib.no). In 2005, about 15 persons were working full-time with integrating, analysing and improving the OGCMs in use. The group in Oslo is smaller, with an effort of 3-5 person years.

The following OGCMs are in use in Norway for climate studies:
1) HYCOM/MICOM (both in Bergen and in Oslo)
2) MITgcm (in Bergen)
3) ROMS (in Bergen)

The activity with HYCOM/MICOM is largest, representing about 80% of the total effort. It should be mentioned that 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). Likewise, the Meteorological Institute version of MICOM is the ocean part of the Oslo Regional Climate Model covering the northern North Atlantic and the Arctic Ocean.

The following classes of studies are carried out:
1) Large-scale and interannual to decadal time scale climate studies (MICOM and ROMS, both fully coupled to dynamic/thermodynamic sea ice modules)

2) Large-scale and interannual to decadal time scale ecosystem and carbon cycle studies (HYCOM/MICOM)
3) Process studies (all model systems)
4) Data assimilation (HYCOM)

Status of the 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) A global model with grid focus in the Atlantic Ocean (35 isopycnic layers; 80 and 40 km horiz resolution in the focus region; grid poles over Europe and N America). (ii) A 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) A global version with poles over Siberia and Antarctica (35 isop layers; 1.5 cos(φ) (Mercator) horizontal resolution), and with enhanced meridional resolution along equator. Model (iii) forms the ocean component of the global coupled Bergen Climate Model (BCM). A major achievement with version (iii) has been completion of the IPCC 4AR runs (BCM is here run without any form of 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 extended
- 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
- 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

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Development of new 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.

The new OGCM is expected to be operational sometime in 2007, and it is a candidate for the next generation of climate OGCM at NERSC/BCCR.

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)

Status Oslo Regional Climate Model (ORCM) (Lars Petter R¿d/Jens Debernard)
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

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

Status of the 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

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.

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.

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C8 Community Climate System Model (CCSM) Ocean Modeling Activities (M Holland)

The Community Climate System Model, version 3.0 was released to the community in June of 2004. The ocean component of this model is based on the Parallel Ocean Program (POP) 1.4. The sea ice model is based on the Los Alamos National Laboratory (LANL) CICE code. The ocean/ice model has two standard resolutions, a nominally 1-degree resolution (gx1) with 40 vertical levels and a nominally 3-degree resolution (gx3) with 25 vertical levels. The ocean/ice models use a rotated orthogonal grid in which the north pole is smoothly displaced into Greenland.

Numerous integrations were performed using the CCSM3 for the Intergovernmental Panel on Climate Change fourth assessment report (IPCC AR4). These include an 1870 pre-industrial control simulation, present-day control simulations, ensembles of 20th century integrations, future scenario runs (Ensembles of A2, A1B, B1 and commit scenario), and 1% increasing CO_2 runs. Numerous aspects of these simulations have been analyzed and a special issue of the Journal of Climate on the CCSM3 is currently in press. Copies of the papers that will appear in this issue are available from http://www.ccsm.ucar.edu/publications/jclim04/Papers_JCL04.html. The ocean analysis presented in these papers includes: Attribution and impacts of upper ocean biases in CCSM3 (Large and Danabasoglu); Diurnal coupling in the tropical oceans of CCSM3, (Danabasoglu et al.); Ocean CFC and heat uptake during the 20th Century in CCSM3, (Gent et al.); Influence of the ice thickness distribution on Polar Climate in CCSM3 (Holland et al.) and influence of sea ice on ocean heat uptake in response to rising CO_2 (Bitz et al.). There are also ocean and sea ice analysis contributions to numerous other manuscripts in this special issue.

In future developments for the CCSM model, work is underway to adopt POP2.0. This model includes software engineering improvements, a tripole grid option, and additional features. POP 2.0 has been validated at NCAR and a number of model developments will be incorporated into POP2 in 2006. Coordinated Ocean Reference Experiments (CORE) will be run with these new physics in the near future.

Specific model developments that are underway and may be used in these experiments include: modified advection schemes, gravity current entrainment parameterizations, a transition layer parameterization, an anisotropic Gent-McWilliams parameterization (Smith and Gent, 2004), and a number of modifications designed to improve the ocean simulation biases in the tropics. The model developments to improve gravity current entrainment and the simulated transition layer also contribute to the Climate Process Teams (CPTs) on gravity current entrainment and eddy-mixed layer interactions, respectively. Sea ice model developments are also underway and include: an explicit melt pond parameterization, improved treatment of shortwave radiation, improved snow model physics and alternative ridging parameterizations.

C9 Update on the development of NEMO (Nucleus for European Modelling of the Ocean, a numerical platform for ocean modelling) (A-M Treguier).

The NEMO system has evolved from the OPA8.2 ocean modelling code (Madec et al, 1998) developed by the French CNRS in Paris. The idea is to bring together expertise and human resources from different European institutions to share the development efforts and have a larger base of users. So far NEMO consists of:
- models of the ocean (OPA 9), sea ice (LIM), passive tracers and biogeochemistry;
- ocean model configurations: the global ORCA2 model and idealized configurations. Also being developed (but not part of the standard system) are global models at 1°, 1⁄2° 1/4° and 1/12° resolution, all based on the same family of tripolar grids;
- scripts to compile and run the models
- a few pre and post-processing tools (in development).

The system is available at www.lodyc.jussieu.fr/NEMO under a GPL-type license. Users include a number of French laboratories (for global climate as well as regional model studies), the French operational oceanography center Mercator-Ocean, 5 laboratories in Italy, three in Germany, four in the UK (the U.K. commitment to NEMO is likely to grow in 2006), and others in Canada, Belgium... NEMO faces challenges: how to perform an efficient maintenance of the system by a European consortium of laboratories and how to develop scientific discussions and collaboration among a growing number of users.

The OPA ocean model development at present is largely driven by the immediate need for regional and operational applications: an explicit free surface has been implemented for modelling of the tides and open boundary conditions have been updated. More accurate pressure gradient formulations adapted to terrain-following coordinates are under investigation. Recently, the momentum advection scheme has been changed to make it more accurate for partial cell topography; this has had an unexpectedly large (and beneficial) effect for the global 1⁄4° model run within the French-German DRAKKAR project.

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