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WGCM/CLIVAR Working Group on Ocean Model Development

Report of the 4th Session

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CLIVAR is a component of the World Climate Research Programme (WCRP), which was established by WMO and ICSU, and is carried out in association with IOC and SCOR. The scientific planning and development of CLIVAR is under the guidance of the JSC Scientific Steering Group for CLIVAR assisted by the CLIVAR International Project Office. The Joint Scientific Committee (JSC) is the main body of WMO-ICSU-IOC formulating overall WCRP scientific concepts.

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1. OPENING AND ORGANIZATION

The fourth session of WGOMD was held at the Citadel Conference Centre in Villefranche-sur-mer, France, April 13-15, 2003. The chairman, Claus Böning welcomed 17 participants (see Appendix B) from major climate, ocean, and ocean-ice modelling groups, to discuss the status and ongoing efforts in the development and assessment of the ocean component models used in climate studies. Dr. Böning emphasised that in response to a request of the CLIVAR SSG and the CLIVAR Atlantic Panel, one session of this meeting will be held jointly with the CLIVAR Atlantic panel to facilitate and foster co-operations between these two groups.

2. REVIEW OF RELEVANT WCRP AND RELATED ACTIVITIES

2.1 News from the CLIVAR Project Office

Howard Cattle, director of the ICPO gave an overview about recent developments in the ICPO and relevant action items from the last session of the Joint Scientific Committee (JSC) of WCRP.

Staff changes in the CLIVAR IPO

The International CLIVAR Project Office (ICPO) has undergone some staff changes. Howard Cattle, formerly at the Met Office took over the director's position from John Gould who retired in summer 2002. Daniela Turk, responsible for the CLIVAR Pacific and Carbon initiatives left the ICPO. Her successor is Katy Hill who joined the office in November. Katherine Bouton left the office end of 2002. At present, the ICPO staff members and their responsibilities are as follows:

- Howard Cattle (SOC)	Director, CLIVAR Scientific Steering Group
- Roberta Boscolo (Vigo)	CLIVAR Atlantic and Variability of the African Climate System (VACS)
- Carlos Ereño (Buenos Aires)	Variability of the American Monsoon Systems (VAMOS)
- Mrs. Sandy Grapes (SOC)	Secretary and administration
- Ms Katy Hill (SOC)	CLIVAR Pacific & Data Management
- Michael Sparrow (Bejing)	Southern Ocean Panel
- Andreas Villwock (Kiel)	Working Group on Seasonal to Interannual Prediction (WGSIP), Working Group on Coupled Modelling (WGCM), Working Group on Ocean Model Development (WGOMD), PAGES/CLIVAR Working Group, CLIVAR Exchanges, CLIVAR Web.
- Zhongwei Yan (SOC)	Asian-Australian Monsoon Panel and Expert Team on Climate Change Detection

In addition, the ICPO is supported by Mrs. Valery Detemmerman from the Joint Planning Staff of WCRP in Geneva, Switzerland.

CLIVAR funding

The CLIVAR Project Office receives funding from various resources. In 2002, the office was supported by UK NERC through JRD/SOC, the US CLIVAR Interagency Group, Canada, France, Germany, Japan (JAMSTEC), UK (Met Office) and JPS for WCRP (travel). In 2003, the level of funding is in general declining which has already a considerable impact on the CLIVAR Newsletter Exchanges. Efforts are under way to seek for new funding resources.

CLIVAR Exchanges

After 7 years the layout of the CLIVAR newsletter Exchanges has been revised and 3 issues with the following foci were published in 2002:

- Tropical-extra-tropical interactions (March)
- CLIVAR Pacific (June)
- CLIVAR Atlantic (double issue, September)

The most recent one (March 2003) highlights science related to the WOCE-CLIVAR transition. Due to the growing interest of the community the size has grown to 40-60 pages with about 1700 subscribers per issue. Due to funding cuts changes of the scope and size of the newsletter are currently under discussion.

CLIVAR Open Science Conference planned for 2004

An international open science meeting to review the first period of the CLIVAR programme is planned for 21-25 June 2004 in Baltimore, USA. The venue and format of the meeting were presented during the joint part of the meeting with the CLIVAR Atlantic (see section 9.5, page 23).

2.2 24th session of the Joint Scientific Committee (JSC) of WCRP

At the 24th JSC session, the CLIVAR presentation was well received with the view that good progress is being made across a range of activities.
The discussion included:

- Data management issues - WOCE shining example
- What is lost from closure of WOCE that CLIVAR won't pick up
- Contribution of CLIVAR for ocean observations network more generally
- Strong support for ocean reanalysis activity; WGNE interest in reanalysis more widely
- Support for AMMA and extension to role of Atlantic, but need also to consider wider aspects of African climate and role of Indian Oceans
- Monsoon activities - role of Chinese landmass, Tibetan Plateau etc
- Need for continued effort in building links with IGBP, IHDP. START, CLIMAG, etc

The key decisions of the JSC meeting can be summarized as follows:

- The aims of WCRP to remain as originally specified
- A concept of a Climate System Observing Prediction Experiment (COPE) as banner activity should be developed, comprising hindcasting from 1979-2009 and prediction to 2020 of coupled atmosphere, ocean, land and cryosphere (+ biosphere etc…)
- The JSC will, after consultation, list a set of themes which will provide a set of foci for WCRP projects
- The initial thrust on seasonal to interannual timescales to be led by WGSIP
- The remit of WGSIP to be extended to decadal timescales
- A "Modelling Council" should be established which also covers climate system data assimilation and model initialisation (DAMI) (Chair Shukla) In addition, an observations Council which also covers WCRP data management issues (DM) should be established
- DAMI & DM will be overlapping between the two
- The reporting to JSC should be linked more to how projects deliver to cope, starting with Seasonal to Interannual Prediction next year.

2.3 6th JSC/CLIVAR Working Group on Coupled Modelling (WGCM)

Claus Böning reported about the action items relevant to WGOMD that arose of the last session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) that took place October 7-10, 2002, Victoria, Canada.

- WGCM welcomed the P-OMIP activity but recommended WGOMD to a) connect the timelines with AMIP and CMIP in order to meet the IPCC requirements and b) to look systematically into the ocean components of coupled model (runs).
- WGCM endorsed the present membership but recommended that future changes should reflect a better representation of the variety of ocean models used and developed at present within the community.

WGOMD took note of both recommendations and will make efforts to meet them to the extent possible. With respect to the membership it noted that compromises are inevitable due to a number of constraints (e.g. representation of ocean *and* climate modelling institutions, geographical distribution), but attempts have and will be made to overcome possible problems by inviting additional experts to its meetings.

2.4 Developments in the ACSYS/CliC - NEG; in particular, report of the NEG meeting on Southern Ocean-Ice - Ocean Modelling (A. Beckmann)

A. Beckmann reported about recent developments in the ACSYS/CliC – NEG. The last session took place in Yokosuka, Japan, 9-12 Sept. 2002. The 4th session of the NEG will be held in Fall 2003 in Victoria, Canada, jointly with the ACSYS/CliC Ocean Products Panel.

The main activities of this numerical experimentation group are:

SIMIP2 (Sea Ice Model Intercomparison Project)

This MIP focuses on an intercomparison of thermodynamic sea-ice components. So far it is developing slowly with only 3 groups participating. A small workshop is planned for fall 2003 back to back to the next session of the NEG. F. Bryan pointed out that a third phase of SIMIP is unlikely to happen in time of the next IPCC assessment.

Ice Sheet Model Intercomparison

This MIP is at present under consideration to follow-up on the EU-project EISMINT. The focus will initially be on grounding line processes and higher-order 3-D models. A small workshop is planned later this year in Europe to set up a protocol and schedule. A larger meeting to wrap-up this activity is planned in about 3 years time.

Permafrost Modelling

This activity which is presently in an early stage will focus a detailed process modelling study. It is planned to use large-scale model results to infer permafrost changes. A workshop in 2004 funded by IARC bringing together process and large-scale modellers and remote sensing people is currently under discussion.

Other NEG co-sponsored activities:
Arctic Ocean Model Intercomparison Project (AOMIP)
(http://fish.cims.nyu.edu/project_aomip/overview.html)

The Arctic Ocean Model Intercomparison Project (AOMIP) is an international effort to identify systematic errors in Arctic Ocean models under realistic forcing. The main goals of the research are to examine the ability of Arctic Ocean models to simulate variability on seasonal to interannual scales, and to qualitatively and quantitatively understand the behaviour of different Arctic Ocean models. AOMIP's major objective is to use a suite of sophisticated models to simulate the Arctic Ocean circulation for the periods 1948-2002 and 1901-2002. Forcing will use the observed climatology and the daily atmospheric pressure and air temperature fields. Model results will be contrasted and compared to understand model strengths and weaknesses.

The project initially focused on the evaluation of Arctic Ocean model output with various active subprojects. Now, coordinated model experiments are underway with 19 participants from 11 institutions. The spin-up runs from 1948-78 are underway, experiments for the period 1979-2002 will follow. More details in section 8.

Arctic Regional Climate Model Intercomparison Project (ARMIP)
(http://paos.colorado.edu/~curryja/arcmip/index.html)

This joint activity with the GEWEX Working Group on Polar Clouds focuses on RCM experiments using common limited domain and boundary conditions for the period Oct. 97-Oct. 98. 4 of 5 participating groups have already completed their simulations.
For the future larger domain experiments are planned and a closer cooperation with WGOMD is envisaged. The group has some interest to use the forcing protocol and forcing data for global sea ice and ocean model intercomparisons, and diagnostic projects related to polar oceans and their ice cover.

3. REVIEW OF OCEAN MODEL DEVELOPMENTS

3.1 Global Ocean Climate Modelling at GFDL (Stephen Griffies)

GFDL ocean model development during the past 3 years has focused on producing a new version of the Modular Ocean Model (MOM) within GFDL's Flexible Modelling System (FMS). FMS is a software infrastructure and superstructure providing common interfaces, tools, and support for earth system modelling. Version 4 of MOM (MOM4) was released to a beta-community April 2002, the second beta version was released in August (physical integrity and bug fixes). The frozen version of MOM4 is expected for summer 2003. This will include refined elements of the portability (based heavily on user input and collaborations), model data flow (more derived types for easier ODA and coupled applications), new physics algorithms, refined FMS infrastructure (coupler, tracer manager). Further updates coincident with FMS public releases are planned every 4-6 months.

Key characteristics of MOM4 include: (1) Fortran 90 with physical units MKS. (2) Two-dimensional (latitudinal/longitudinal) domain decomposition is used for single or multiple parallel processors. (3) Model equations are formulated in generalized orthogonal horizontal coordinates and bottom topography is represented using partial cells. (4) The external mode solver is an explicit free surface. (5) Physical parameterisations are state-of-the art.

The near-term focus of global climate model development at GFDL is within a coupled earth system modelling framework that aims to couple FMS ocean, sea ice, atmosphere, biogeochemistry, and land models. 2-degree and a 1-degree mercator resolution ocean models are planned, each with the same 50 vertical levels and physics. Treatment of the Arctic is via a bipolar grid northward of 65N with coordinate singularities placed over land.
For more information, please see http://www.gfdl.noaa.gov/~fms/ and http://www.gfdl.noaa.gov/~lat/webpages/om/om_webpage.html

3.2 Max-Planck-Institute for Meteorology (Johann Jungclaus)

The new ocean model now named "MPI-OM" (formerly C-HOPE) – Hamburg Ocean Primitive Equation Model on C-Grid has undergone significant development in recent years. Most notable is the treatment of horizontal discretisation which has undergone transition from a staggered E-grid to an orthogonal curvilinear C-grid. The treatment of subgrid-scale mixing has been improved by the inclusion of a new formulation of bottom boundary layer (BBL) slope convection, an isopycnal diffusion scheme, and a Gent and McWilliams style eddy-induced mixing parameterisation. The model set-up described has a north pole over Greenland and a south pole on the coast of the Weddell Sea. This gives relatively high resolution in the sinking regions associated with the thermohaline circulation. In addition, equatorial meridional grid refinement allows for the resolution of equatorial waves associated with the ENSO phenomenon.

This ocean model is used in the new climate model of MPI together with the most recent version of the atmospheric model ECHAM5 coupled through the OASIS coupler without applying any flux correction. The standard version uses an atmospheric resolution of T42 (2.825 deg), with an interactive runoff and glacier calving schemes, whereas the ocean resolution varies as described above from 10-350km). Depending on the application other configurations are possible.

The ocean model is described in detail in:
Marsland, S.J., H. Haak, J. H. Jungclaus, M. Latif, and F. Roeske, 2003: The Max- Planck -Institute global ocean/sea ice model with orthogonal curvilinear coordinates. *Ocean Modelling*, **5 (2)**, 91-127.

Future plans: MPI, the German Weather Service 'DWD' and other German institutions are currently running a new modelling project to develop a new atmosphere model with grid-point based dynamics.

3.3 National Center for Atmospheric Research (NCAR) (William Large)

A most recent version of the NCAR Community Climate System Model (CCSM-2.0) has been released in May 2002 (small update in October). The mode source code, documentation, and some output from a fully coupled control run are available for download at: http://www.ccsm.ucar.edu/

The ocean component of this system is based on the POP 1.4 model from Los Alamos National Laboratory. The standard configuration is run on a dipole grid with the grid North Pole displaced into Greenland and with a nominal resolution of 1 deg. and 40 levels. The transition to a new version of the model (POP2.0) is currently under way. The 1° model is used for IPCC coupling. Major changes encompass:

- KPP boundary layer
- Double Diffusion
- Solar Absorption (Chlorophyll)
- Ideal Age and Passive Tracer Infrastructure
- Ocean Currents in Air-Sea Fluxes

During the next 3-4 years it is planned to use the Ocean Mixing Climate Process and Modelling Team approach (see section 7) to assess and improve the ocean model. Within this time frame an eddy-resolving version of the model should be available for coupling.

3.4 RSMAS/LANL: Hybrid Coordinate Ocean Model (HYCOM) (Eric Chassignet)

The hybrid coordinate is isopycnal in the open, stratified ocean, but smoothly reverts to a terrain-following coordinate in shallow coastal regions, and to pressure coordinate in the mixed layer and/or unstratified seas.
The capability of assigning additional coordinate surfaces to the oceanic mixed layer allows for sophisticated closure schemes in HYCOM:

- Continuous Vertical Mixing Models (surface to bottom)
  - K-Profile Parameterization, i.e., KPP (default)
  - Mellor-Yamada level 2.5 turbulence closure
  - Canuto/GISS

- Slab Mixed Layer Models
  - Kraus-Turner
  - Price-Weller-Pinkel dynamical instability model

- Compared in low-resolution climatological Atlantic simulations [Halliwell, 2003, available on HYCOM web site]

Vertical Mixing Scheme Evaluation Summary

- The largest observed differences among the vertical mixing choices result from:
  - Penetrating short-wave radiation
  - Shear instability mixing below the mixed layer

- KPP mixing chosen as the default mixing scheme
  - Parameterizes more physical processes than other schemes
  - Performed well in tests
- Other mixing algorithms allow one to determine the sensitivity of scientific results to vertical mixing

Status of HYCOM Development

HYCOM 2.0 (released 3 July 2001)

- Scalability via MPI and/or OpenMP (2 1000 cpus)
- Fortran 90 coding style
- Single source code for all machine types
- Bit-for-bit multi cpu reproducibility

Nesting

- Off-line and one-way
- Based on enclosing region's archive files

MICOM compability

- MICOM-like mode
- Can continue a true MICOM simulation
- Convert MICOM-like to HYCOM-mode
- Add layers near the surface

Diagnostics

- Layer snapshots and animations
- Cross-section snapshots and animations
- Means and variabilities
- Transport sections

HYCOM 2.1 (Released in September 2002)

- Add halos for MPI to automatically support periodic
- boundaries
- Support nested-domain open boundaries
- Fully global (Pan-Am grid)
- Alternative mixed layer models
    - Mellor-Yamada 2.5
    - Price-Weller-Pinkel
- Orthogonal curvilinear grids
- Passive tracers, floats
- NPZD model
- NetCDF output files
- User's manual and guide available

3.5 Global Ocean Climate Modelling at CSIRO and Antarctic CRC (Anthony Hirst)

The main work on coupled climate modelling in Australia involves development of the CSIRO Mk 3 coupled climate model and the CSIRO-BMRC seasonal prediction model. The former is developed primarily for the purpose of multi-century climate integration and climate change projection, though a seasonal prediction capability is also available. The latter is used exclusively for seasonal prediction, and includes a data assimilation system which has been extensively tested using tropical Pacific data. Both models feature MOM-based ocean components.

Major Modelling Projects in Australia

POAMA seasonal prediction model

- CSIRO Marine Research/BMRC *(Schiller, Alves)*
- coupled model, global domain
- ocean code MOM 2 (upgrade to MOM 4)
- enhanced ocean resolution in tropics (0.5º lat. x 2.0º lon.)
- tropical Pacific data assimilation
- 6 month prognostic integrations now used operationally

Stretched-grid eddy resolving ocean model

- CSIRO Marine Research/BMRC *(Schiller, Smith)*
- global domain, 10-12 km resolution near Australia
- Ocean code MOM 4
- global data assimilation system
- part funded by the Australian Navy
- short term (days, weeks) prediction of oceanic thermal structure

The ocean component of the CSIRO Mk 3 coupled climate model is being upgraded to MOM 3.1. There has been considerable work to increase the computational efficiency of this model (in stand-alone ocean mode) on the NEC SX5 machine. The model resolution is 0.9° lat. by 1.8° lon. with 31 levels in the vertical. Details of the model remain as indicated on the web pages at http://www.clivar.org/publications/wg_reports/wgcm/wgomd_table.pdf, except that the Chen et al. scheme has been implemented to handle upper ocean mixing processes. It has not been practicable so far to participate in P-OMIP, in part for technical reasons (e.g., the sea ice model is encoded with the atmospheric model making the performance of a sea ice-ocean integration non trivial). However, in joint work with the Antarctic Co-operative Research Centre (CRC), University of Tasmania, a revised ice model is being directly coupled to the Mk 3 stand-alone ocean model, which may facilitate easier participation in the next phase of P-OMIP.

CSIRO Mk 3 coupled climate model

- CSIRO Atmospheric Research/CSIRO Marine Research/Antarctic CRC *(H. Gordon, Hirst, McDougall, Matear, Murray)*
- coupled model, global domain
- ocean code MOM 2 (upgrade to MOM 4)
- ocean resolution (0.9º lat. x 1.8º lon., 32 levels)
- biogeochemical ocean model
- part funded by Department of Environment
- simulation of climate change (IPCC, CMIP, …)

In other ocean modelling work, Nathan Bindoff and Jason Roberts, both of the Antarctic CRC, have configured a 1/8° ocean model (80° N to 80° S), based on the MOM 3.1 code, under a Tasmanian Programme for Advanced Computing grant. The model runs very efficiently using MPI on 64 CPUs (16 nodes) of a Compaq ES45 cluster. One of the motivations is the determination, in collaboration with Trevor McDougall of CSIRO, of eddy transport fluxes to test parameterisations used to include meso-scale eddy effects in non-eddy permitting models such as the CSIRO Mk 3 ocean component. The simulations for this purpose are to have seasonless surface forcing, which allows clearer diagnosis of the eddy statistics.

TPAC eddy-permitting ocean model

- Antarctic CRC/CSIRO Marine Research *(Bindoff, McDougall)*
- 1/8° global domain
- Ocean code MOM 3 (upgrade to MOM 4)
- funded by TPAC (Tasmanian Partnership for Advanced Computing)

Some details of the TPAC model:

Resolution:
- MOM 3.1
- 80ºS to 80ºN model
- 1/8º lat x 1/8º long x 24 vertical levels
- Partial cells for bottom most level

Computational Hardware
- Running on APAC facility (Compaq ES45 cluster)
- Using MPI for 64 CPU's (16 nodes of 4 CPU's each)
- 6 days for one model year

Modelling Projects (UTas with CSIRO Marine Research)
- Mesoscale eddy parameterisation with seasonless forcing, 20 year integration now complete and under analysis
- Validation of Global Change on the Southern Ocean since the 1950's (starting Q2, 2002), using NCEP reanalysis data

3.6 Earth Simulator (Hiroyasu Hasumi)

Earth Simulator, a super computer which has the theoretical maximum speed of 40 TFLOPS, is to be shared by researchers of climate, seismology, and computer sciences. A large part of the computer resource is assigned to a grant-in-aid research project set up by Ministry of Education, Culture, Sports, Science and Technology. The project is five-years long starting from 2002, consists of several subjects, and only one proposal is accepted for each subject. The proposals are now under review. In the climate modelling area, there are four subjects:

1. High resolution coupled atmosphere-ocean modelling
2. Development of an integrated model for global warming prediction (land and ocean ecosystems coupled modelling)
3. Sophistication of parameterisation of physical processes
4. Development of a high-precision, high-resolution climate model (regional-scale super-fine resolution atmospheric modelling)

The following projects are currently under development:

Earth Simulator Center
Model: OfES (OGCM for Earth Simulator, based on MOM3)
Resolution; 0.1 deg., 50 levels (poleward of 75 deg is excluded)
Aim: evaluate the role of meso-scale eddies in forming the ocean general circulation
Current status: 50 yr integration finished

Frontier Research System for Global Change (Climate Variations Research Programme)
Model: POM
Resolution: 0.1 deg, 55 levels (Arctic Ocean is excluded)
Aim: short-term ocean prediction around Japan -> nesting of a higher resolution regional model
Current status: 50yr of 100 yr spin-up integration finished

Central Research Institute of Electric Power Industry
Model: POP
Resolution: 0.1 deg
Current status: 10yr integration finished
IPCC SRES runs in collaboration with NCAR

Center for Climate System Research
Model: COCO (CCSR Ocean Component Model), AGCM coupled
Resolution: 1/4 deg. (longitude x 1/6 degree (latitude), 48 levels
Aim: IPCC SRES runs
Current Status: coupled model tuning (OMIP-style 100 yr integration of the ice-ocean component model is also underway)
Intercomparison of high resolution coupled models with HadCEM

More information can be found at http://www.es.jamstec.go.jp/

3.7 Recent activities with the Poseidon OGCM (Paul Schopf)

Poseidon is a non-Boussinesq ocean circulation model, written with a generalized vertical coordinate and orthogonal curvilinear coordinate using finite volume techniques. The vertical coordinate is typically used as a hybrid isopycnal-pressure coordinate, not unlike HYCOM's current use. Optionally, a mixed layer and buffer region are used at the surface.

The model is coded on both the B- and C- grids, with run-time selection based on restart files. In the C-grid mode, vector- invariant dynamics are used with either Arakawa-Hsu 2nd order vorticity advection or Suarez-Takacs 4th order. Recently a split explicit barotropic solver has been added, following Hallberg (1997). Quadratic spline remapping is used in the vertical. The addition of the barotropic mode has led to adoption of the Lin (1997) Jacobian form for pressure gradient.

The model is coded with the GEMS parallelization libraries, and runs efficiently on a wide variety of architectures, from laptops to the HP Compaq AlphaServer at NASA GSFC and the IBM SP clusters at NCAR. The primary application is the NASA NSIPP prediction effort and ENSO modelling at COLA.

3.8 **Hadley Centre** (submitted by Malcolm Roberts)

HadCEM - eddy permitting coupled climate model

A coupled model with an eddy-permitting ocean (HadCEM) has now completed a 150 years control run and an 80-year idealised climate change run. The model is a development of the successful HadCM3 model and uses exactly the same atmospheric and sea-ice components, and an ocean with a 1/3 degree resolution. (http://www.metoffice.com/research/ocean/climate/development.html)

More model characteristics

- 1/3°x1/3°x40 level ocean model, 2.5°x3.75° HadAM3 atmosphere
- Completed 70 year spin-up + 80 year control run + 80 year 2% CO_2 run
- Improvement in overall model simulation, particularly large-scale ocean transports
- Some interesting differences in climate change response in Atlantic compared to low resolution run
- Submitted paper available from http://www.clivar.org/publications/papers/hadcem_co2_single.pdf Comments are welcome.

Preliminary conclusions from HadCEM

- Need higher atmospheric resolution to fully realise ocean improvements
- Downstream overflows still poorly represented
- Surprising lack of change in ENSO character, despite more oceanic variability
- Work proceeding to port model to Earth Simulator (5 day run completed, March 2003), with a view to running IPCC scenario runs, and coupling to higher resolution atmosphere model

Hadley Centre Global Environmental Model vn1 (HadGEM1)

A new coupled model (HadGEM1) is being developed at the Met Office (due to complete testing late 2003), incorporating an atmosphere with an entirely new semi-implicit, semi-Lagrangian dynamical core. The ocean component will again be based on that in HadCM3, with a basic 1-degree resolution, narrowing to 1/3 degree meridionally near the equator.

More model characteristics

- New atmospheric model - semi-implicit, semi-Lagrangian dynamics, new physics, 1.25°x1.875° resolution
- Ocean model of 1° resolution on lat/long grid, with enhanced meridional resolution of 1/3° in tropics, 40 levels
- Implicit free surface with full explicit freshwater flux forcing
- Simple bottom boundary layer parameterization (Beckmann and Döscher 1997)
- Partial cell bathymetry
- EVP sea-ice model with multi-category ice thickness distribution
- McDougall et al. (2002) equation of state
- Currently in testing phase

4. OCEAN REANALYSIS AND DATA ASSIMILATION

The Working group met jointly with the Atlantic Implementation Panel for a short session on ocean reanalysis and data assimilation. D. Stammer reported about methods for rigorous data assimilation. Amongst other efforts like GODAE (Global Ocean Data Assimilation Experiment) and Mercator, representing the French contribution to GODAE, Stammer highlighted the ECCO ("Estimating the Circulation and Climate of the Ocean") project. ECCO is a consortium between scientist at JPL, MIT and SIO. It is funded under the National Oceanic Partnership Program (NOPP) with funding provided by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Office of Naval Research (ONR). The first phase of ECCO ends in 2004.
The ECCO Consortium uses rigorous global ocean state estimation methods to produce dynamically consistent time-varying model/data syntheses over the 10+ year period from 1992 to present as the basis for studies of a variety of scientific problems. Rigorous estimation methods are computationally demanding. However, they are essential in obtaining dynamically self-consistent estimates useful for understanding the physics of the time-evolving ocean and its interaction with the atmosphere by exploiting the information contained in ocean and satellite data.

ECCO estimates are based on the MIT general circulation model (Marshall et al., 1997), which employs advanced mixed layer physics and an eddy parameterization scheme. Ongoing efforts of the ECCO Consortium consist in producing two sustained near global ocean estimates: (1) A near-real-time product on a nominal 1^{o} horizontal grid telescoping to $1/3^{o}$ toward the equator with 46 levels assimilating altimetric sea surface height and *in situ* temperature profiles using a Kalman filter-smoother, (2) A product assimilating all available data on a 1^{o} horizontal grid with 20 levels using an adjoint model. Both estimates are forced by daily heat and freshwater fluxes and twice-daily wind stress fields.
The results from those two products are available to the public and are distributed through the internet. They can be accessed via the consortium's data server (http://www.ecco-group.org/data_server.html). Model output comprises weekly to monthly averages of the full model state, twice-daily sea surface height and bottom pressure fields, as well as the surface forcing fields that are part of the estimated solution. Other fields or additional diagnostics can be made available upon request. See http://www.ecco-group.org for details. A release and full documentation of both forward and adjoint ECCO codes is available at http://mitgcm.org/sealion. Applications of ECCO products are manifold and include: ocean dynamics, parameter testing, surface fluxes/bio-geochemistry estimation and initialisation of coupled models. Some of the remaining issues in the context of ocean data assimilation are:

- Improving prior process and error statistics
- Improving model and resolution
- Extend the control space to include model error
- Extend the estimation period
- What data are required?
- Where can all required input fields be obtained.
- Sustained support: man and computer power

Two Workshops are currently being planned which are mainly focussing on ocean reanalysis but will also address atmospheric reanalysis and coupled efforts. The first one is a NSF-ONR sponsored US Workshop on "Progress and Prospects of Data Assimilation in Ocean Research" to be held in Williamburg, VA, Sept. 9-11, 2003. The goals of this planning workshop are to:

1. Assess the state of the art in data assimilation and discuss what new research will be required to realize the full potential of data assimilation and new observational methods for sciences and operational purposes.
2. Summarize the status of major national ocean data assimilation efforts and enumerate their impact in the U.S.
3. Review remaining challenges and discuss benefits from addressing them for science and operational assimilation efforts.
4. Identify potential mechanisms for providing long-term funding support for sustained assimilation efforts, for advancements in data assimilation approaches, and for expansions of applications.

5. Develop mechanisms for interactions between research-oriented efforts and those at the operational centres.
6. Discuss needs for educating, training and retaining scientists involved in data assimilation for both research and operations.

The second workshop is an international CLIVAR Workshop on Ocean Reanalyses which has the following objectives:

- review the status of ongoing and planned ocean synthesis (reanalysis) efforts
- establish the requirements for ocean state estimation and reanalysis in climate research within the remit of CLIVAR,
- promote the use of existing reanalyses,
- review the synergy between ocean and atmospheric reanalysis activities with specific focus on improving surface flux fields,
- review coupled ocean-atmosphere model synthesis in support of climate prediction.

The outcome of the workshop should be:

- A summary of the status of ongoing efforts in the ocean and atmosphere and their results.
- An overview of requirements for ocean reanalyses for a range of climate research activities.
- A strategy to develop sustained syntheses of satellite and *in-situ* observations of the ocean suitable to support climate research.
- A strategy to bring ocean and atmosphere syntheses into a coupled reanalysis that conserves key properties.

Meeting Format and timing

The meeting will be open to the community but limited in size. The anticipated number of attendees: 50-80. The meeting will consist of plenary sessions with invited talks followed by working sessions in which discussions will be held that focus on addressing the meeting's outcomes.

Topics

I) The requirements for Ocean Reanalyses:

- Ocean synthesis requirements, benefits and strategies
- Status of atmospheric reanalyses
- Data assimilation approaches
- Data and model requirements
- Computational and infrastructure requirements
- Missing parts

II) Summary of ongoing activities in the ocean (e.g.: ENACT, ECCO, Mercator, GODAE, etc

III) Fluxes from Atmospheric reanalyses (e.g. ECMWF (ERA-40), NCEP, DAO, SURFA)

IV) Applications of reanalysis efforts:

- Improving Ocean-Atmosphere fluxes
- Defining ocean variability
- Estimating ocean mixing
- Quantifying seasonal to interannual variations
- Anthropogenic change
- Sea level rise

V) Ocean observing system for CLIVAR:

- Observations from *in situ* and VOS platforms (availability and identified gaps).
- Satellite observation needs.
- Data flow, QC and archiving.
- Requirements over and above those specified by GOOS/GCOS

VI) Uncertainties and biases:

- Estimating data surface flux errors.

- Estimating model errors.
- Estimating uncertainties in syntheses.
- Dealing with biases in models and surface fluxes.
- Sensitivity to model physics.
- Identification of deficient model physics.

VII) Challenges for the future:

- Coupled reanalysis approaches
- What new approaches might there be to estimation procedures.
- Resolution and non-linearities
- Required observing and data delivery systems
- Manpower and infrastructure needs.

The proposal for the international workshop will be presented to the CLIVAR SSG for endorsement. The venue of this meeting is currently under discussion.

The participants felt that the topic of ocean reanalysis and data assimilation are of increasing importance. Experience for the atmospheric reanalysis have documented the value of such an endeavour. Systematic intercomparisons of reanalysis and models will be a useful tool for ocean model testing and development and thus provide a link into WGOMD. In turn it was noted that a systematic assessment of global ocean models as being planned in OMIP, will provide guidance of the forward models in the assimilation systems. Both panels welcomed the planned international workshop as an important cornerstone for a comprehensive assessment and future planning.

5. OCEAN MODEL INTERCOMPARISON PROJECT: Status of the pilot phase (P-OMIP) (A.-M. Treguier)

5.1 OMIP Protocol

The OMIP protocol has been finalized but some choices are left open. It is much more difficult to make a strict protocol for ocean/ice models than it is for coupled models including the atmospheric component.

OMIP-Forcing Version 2.1

F. Roeske presented a revised version of the OMIP forcing that has been developed to address some problems with the version currently used in P-OMIP. In the precipitation dataset negative values were removed while keeping the global average constant. River runoff was calculated by using this modified data set.
Spectra from the mean annual cycle (MAC) as well as from all single 15 years of the ECMWF Re-Analysis (ERA) were derived and net heat fluxes in the El Nino regions were calculated in order to demonstrate that the El Nino year 1982 does not dominate the variability of the MAC.
New formulae from Birol Kara are used for the drag coefficients of the turbulent heat fluxes which produce more realistic values at low and high wind speeds. They were fitted to the TOGA COARE algorithm version 2.6.
The artificial additional factor 2 in the southern hemisphere ice regions to close the global heat budget has been removed. Instead, an inverse method after Isemer et al. 1989 and da Silva et al. 1994 was used. However, it is not possible both to keep the parameters inside the given range of uncertainties and to match all the heat transport observations. One possible solution is to consider katabatic winds which might not be simulated adequately by the ECMWF model. For this purpose, a little scheme was developed.
The OMIP forcing is available now at a new address: http://www.omip.zmaw.de/omip.php.

Reference:
Kara, A. B., P. A. Rochford, and H. E. Hurlburt, 2000: Efficient and accurate bulk parameterizations of air-sea fluxes for use in general circulation models. *J. Atmos. Ocean. Tech.*, **17 (10)**, 1421-1438.

5.2 Contributing models and institutions

Currently there are 6 contributors to P-OMIP. Four (U. Miami/LANL with MICOM/HYCOM, CCSR, MRI and GFDL/IARC) have set up a website. LODYC and MPI have not yet put up results on the web. The participating models have very similar spatial resolution (generally 2° in longitude with refinements).
The information on the various web-sites is not complete. Some model details are given, but not all of them (see summary in Tables 1 (page 18) and 2). The same is true for model parameters (table 2) and for compliance with the OMIP protocol (table 3).

Table 2: OMIP Model parameters

Parameters (MKS)	MOM/ GFDL	CCSR	MRI	OPA/LODYC	MPI	MICOM/HYCOM
Resolution	2°	1°	2°	2°	3° or 1.5°	2°
Horizontal viscosity	variable	30,000	50,000	40,000 (less in tropics)	variable	
Vertical viscosity		10^{-4}		$1.2\ 10^{-4}$ +TKE	variable	
Isopycnal diffusivity	800	1000	1000	2000	1000 (grid size dependent)	
Vertical diffusivity	$5\ 10^{-6}$ to 10^{-4}	10^{-5} to $3\ 10^{-4}$	10^{-5} to $2.7\ 10^{-4}$	$1.2\ 10^{-5}$ +TKE	variable	$2\ 10^{-7}$ /N
Eddy induced	800	300	1000	2000	0.5*isopycnal diff.	

Table 1: OMIP Models

Model/Institution	Sea Ice	Model equations	Horizontal grid	Vertical grid	Physics
MOM4 / GFDL-IARC **Simmons and Griffies**	GFDL SIS (Sea Ice simulator); 2 ice and one snow layer; 5 ice categories	Primitive equations; explicit free surface	2nd order finite difference, B-grid; two poles in the Northern Hemisphere; 2° longitude, Mercator isotropic; refined in the tropics (180x174 points)	z coordinates; 50 levels; partial bottom cell	KPP mixed layer; isopycnal diffusion + GM; diffusive BBL
CCSR **Hasumi and Nakamo**		Primitive equations; rigid lid ?	B-grid; rotated North and South poles; 1° resolution	z coordinates; 40 levels	3rd order advection for tracers; Mellor Yamada mixed layer; isopycnal diffusion GM
MRI **Ishikawa et al.**	Simple sea ice model	Primitive equations; free surface	2nd order finite difference, B-grid; filtering at the North Pole; 2° longitude, 1° latitude	z coordinates; 48 levels	Quick scheme for tracers; Takano-Onishi for momentum advection; Mellor Yamada mixed layer; isopycnal diffusion GM
OPA/LODYC **G. Madec**	LIM ice model (Louvaine la Neuve); 3 layers, 1 category	Primitive equations; implicit free surface	2nd order finite difference, C-grid; two poles in the Northern Hemisphere; 2° longitude, Mercator isotropic; refined in the tropics (182x149 points)	z coordinates; 31 levels	Level 2.5 closure mixed layer; isopycnal diffusion + GM; diffusive BBL
MICOM/HYCOM **Miami/Los Alamos** **R. Bleck**	Simple thermodynamic ice model	Primitive equations; free surface; isopycnic or hybrid vertical coordinates	2nd order finite difference, C-grid; two poles in the Northern Hemisphere; 2° longitude, Mercator isotropic	16 layers	
MPI Hamburg **Haak and Jungclaus**	Dynamic-thermodynamic, 1 layer + snow	Primitive equations, z-coordinate, semi-implicit free surface	2nd order finite difference, C-grid; poles on Greenland and Antarctica, 3°-Version: 120x101x40 grid points 1.5°-Version: 254x220x40 grid points		

Table 3: OMIP model forcing strategies

Model/institution	Compliance to protocol
MOM4.0 / GFDL-IARC Simmonds and Griffies	Uses input OMIP forcing fields, include. Runoffs; uses own bulk formulae
CCSR Hasumi and Nakano	
MRI Ishikawa et al.	
OPA / LODYC G. Madec	Uses input OMIP forcing but different runoffs; uses Kara bulk formulae
MICOM/HYCOM Miami/Los Alamos R. Bleck	Uses input OMIP forcing field as prescribed fluxes; no bulk formulae
MPI, Hamburg Haak and Jungclaus	Full compliance

5.3 Results

The differences between the models seem large enough to motivate interesting analysis (table 4).

Table 4: A few model results (approximate numbers from figures, errors possible, please cross-check)

Results	MON/GFDL	CCSR	MRI	MICOM/HYCOM	MPI[1]	OPA
Global Overturning at 30°N	13 SV	12 SV	10 SV	10SV	18 SV	
Atlantic Overturning at 30°N	14 SV	14 SV	10 SV	14 SV	18 Sv	
Max. global heat transport	1.25 PW	0.8 PW	1.5 PW		1.8 PW	
Max. Atlantic heat transport	0.7 PW	0.4 PW	0.7 PW		1.1 PW	
Drake passage transport	162 SV stable	187 decreasing		140 SV decreasing 170 SV stable	170 SV	
Indonesian throughflow	-13 SV stable	-8 SV decreasing ?		30/35 SV stable	-11 SV	

5.4 Discussion

The group members presented some of the results of the P-OMIP study in more detail and discussed a future strategy. A number of issues were identified such as:

- Scientific questions addressed through OMIP to generate interest (e.g. THC variability)
- Funding for experiments and analysis; role of PCMDI
- Forcing (restrictive vs. open protocol).

The group agreed that the preliminary results available at the meeting already demonstrate that P-OMIP has shown some merit and feasibility and hence it is worthwhile to continue. Nevertheless, a more comprehensive and in-depth analysis is required before enlarging the number of participants. In addition, a full OMIP does require additional resources to perform common data analysis and interpretation. The group agreed to build the future planning on a scientific review of P-OMIP results, as part of the workshop in 2004 (see item 10). In preparation for this event, participants will conduct analysis of P-OMIP output with respect to various themes and processes of interest in the context of the ocean's role in climate.

The discussion on the forcing was more controversial but the group finally agreed that modest modifications to the OMIP protocol should be allowed but have to be well documented.

[1] A later revision of the results showed that the LW forcing field used was incorrect, a new run showed reduced mass and heat transports (Atlantic: 16 Sv and 0.8 PW)

6. REVIEW OF OTHER RELEVANT ACTVITIES

CMIP THC Variability Experiment ("Water Hosing") (S. Griffies)

The aim of this coordinated CMIP experiment is to establish a benchmark for the sensitivity of the Thermohaline Circulation (THC) to an imposed surface freshwater flux. The design is to apply a surface flux of 0.1 Sv in total, uniformly distributed over the Atlantic between 50ºN and 70ºN, for a period of 100 years, starting from a control state. This additional flux is a net addition of freshwater to the ocean; it is not compensated for by removal elsewhere. After 100 years, the imposed water flux will be switched off, and the experiment continued to run, so that any recovery can also be investigated.

Experiments like the 'water hosing' experiment of CMIP are difficult to conduct with ocean-only models. The usual restoring boundary condition on surface salinity overly damps the salinity anomaly and misrepresents the sensitivity of the oceanic circulation. Flux boundary conditions for salinity seem a more natural choice. Combined with restoring conditions for SST mixed boundary conditions are realized. This is the case whenever SST is relaxed to a fixed reference temperature, for instance by using bulk formulas for the latent and sensible heat fluxes where a prescribed air temperature enters. Mixed boundary conditions are known to result in a much too sensitive system where small changes in salinity result in massive changes in the thermohaline circulation (Bryan, 1986; Rahmstorf, 1995; Lohmann et al.,1996). The sensitivity results from the positive salinity advection feedback: Warm and saline water that is carried northward by the thermohaline circulation is cooled in high latitudes, leading to enhanced sinking. The replacement of the sinking water strengthens the thermohaline circulation. In the climate system, the negative temperature advection feedback counteracts the salinity advection feedback. The heat released by the ocean warms the atmosphere and reduces the density gain in the poleward branch of the thermohaline circulation. This feedback is suppressed with prescribed air temperatures in ocean models. Simple atmospheric models have been used to overcome these difficulties (e.g. Rahmstorf, 1995; Lohmann et al., 1996) but are no option for experiments which aim at a close simulation of the observed ocean state and its temporal development. The suggestion of splitting the salinity in two components where one is restored to reference surface salinities while the other integrates the anomalous surface fluxes is under investigation.

WGOMD discussed possibilities to contribute by investigating the oceanic mechanisms involved in the response to freshwater anomalies in greater detail, building on the ocean-ice model participating in OMIP. It was concluded to explore possible forcing scenarios in the next months.
Action Item: S. Griffies and R. Gerdes to explore possible forcing scenarios in the next months.

7. OCEAN MIXING (W. Large)

W. Large reported on the US initiative on Climate Process and Modeling Teams (CPT), in particular for Ocean Mixing. The overall goals for the Ocean Mixing CPT's are:

- To speed development of global coupled climate models and reduce uncertainties.
- By bringing theoreticians, observationalists, process modelers and centers together.
- Teams of PIS and institutions (at least one of GFDL, NCAR, GSFC).
- Faster, more efficient transfer of knowledge

The premises for the Ocean Mixing CPTs are that a) the ocean mixing plays a key role in climate variability and change and b) the mixing is the most uncertain component of modern ocean GCMs. The strategy for the Ocean Mixing CPTs can be summarized as follows:

- To implement and verify improved parameterizations of processes with a mature observational and theoretical bases.
- Data mine and develop observations and theory for processes with less adequate bases.
- To interact with the planning of future field programmes.

The implementation of the ocean mixing CPTs will be done by incorporating:

- Modeling Centers; co-PIS from NCAR, GFDL, and/or GSFC; with institutional commitment. Preference to more than one.
- Process Observationalists; reality check and coordinate planning of new field experiments.
- Process modelers and theoreticians, first line of observation-model interaction.
- Model developers; involve a variety of Ocean General Circulation Models.

The overall budget for the Ocean Mixing CPTs is limited to $1M per team per year over a three year pilot phase with the possibility for a 2 year extension.

Response of Modelling Centres
- Joint participation by GFDL, NCAR, GSFC
- Climate model (~1-2 °) improvement ENSO to decadal within 3 years.
- Processes that most effect climate models.
- Critical mass of scientists
- Robustness across models
- Outreach

Letter of interest for the following topics have been submitted:
- Double Diffusion
- Gravity Current Entrainment
- Vertical Mixing and ENSO
- Tropical Mixing
- Eddy-Mixed Layer Interaction
- Polar Ocean Vertical Mixing
- Tropical Atlantic
- Unified Turbulence Closure

The decision about the funding of one or more CPTs will be done later this year.

The WG thanked Dr. Large for his presentation and discussed in particular possibilities for a liaison of the CPT on Ocean Mixing, with WGOMD activities such as OMIP. It was concluded that a coordinated modelling framework represented by OMIP could provide a useful benchmark for the assessment of the representation of mixing processes in different models and their relevance for the large-scale circulation. The planned workshop on developments of ocean climate modelling would be set with an aim towards assessing the status of the ocean models being used for the next IPCC assessment serving as a benchmark for future developments. (see section 11)

8. POLAR OCEANS (R. Gerdes)

R. Gerdes summarized the recent developments within the Arctic Ocean Model Intercomparison Project (AOMIP) is an international effort to identify systematic errors in Arctic Ocean models under realistic forcing.

The main goals of the research are to examine the ability of Arctic Ocean models to simulate variability on seasonal to interannual scales, and to qualitatively and quantitatively understand the behaviour of different Arctic Ocean models. AOMIP's major objective is to use a suite of sophisticated models to simulate the Arctic Ocean circulation for the periods 1948-2002 and 1901-2002. Forcing will use the observed climatology and the daily atmospheric pressure and air temperature fields. Model results will be contrasted and compared to understand model strengths and weaknesses.

AOMIP will bring together the international modelling community for a comprehensive evaluation and validation of current Arctic Ocean models. The project will provide valuable information on improving Arctic Ocean models and will result in a better understanding of the processes that maintain the Arctic's observed variability.

Participants as of March 2003:

AWI	Alfred Wegener Institut	Germany
GSFC	Goddard Space Flight Center	USA
IOS	Institute of Ocean Science	Canada
LANL	Los Alamos national Lab.	USA
NPS	Naval Postgraduate School	USA
NYU	New York University	USA
RAS	Russian Academy of Sciences	Russia

UAF	University of Alaska Fairbanks	USA
UW	University of Washington	USA
Chair: WHOI	Woods Hole Oceanographic Institution	USA

1. Spin up phase

- Starting from climatological hydrography
- spin up procedure for sea ice
- NCEP/NCAR reanalysis forcing 1948-1978
- surface salinity restoring 1948-1957
- prescribed fluxes 1958-1978
- analysis of seasonal cycle for 1978

The phase is in most parts finished and run in an uncoordinated mode. The only common feature is that the arctic is included in model domain but everything else is different. A paper from Steiner et al. Is in press in Ocean Modelling.

2. Analysis phase

- NCEP/NCAR reanalysis forcing 1978-2000

3. 20th century experiments

- Blend of reconstructed atmospheric forcing data and reanalysis

Model Forcing and Validation Data

- **Bathymetry**: Global merged data product that blends the International Bathymetric Chart of the Arctic Ocean data with the Earth Topography Five Minute data
- **River-runoff**: monthly climatology, gauged & ungauged
- **Sea-ice**: National Snow and Ice Data Center
- **Hydrography**: Global merged data product where various high-quality Arctic Ocean data sets have been blended with the World Ocean Atlas (Steele et al., 2001)
- **NCEP daily SLP** ⇒ surface wind, surface stress (blend of SLP derived winds and NCEP winds for global models)
- **NCEP daily SAT**
- **Relative humidity**: 90% (blended with NCEP product outside of the Arctic for global models)
- **Precipitation**: monthly climatology (Serreze & Hurst, 2000; Xie & Arkin,1996, 97)
- **Clouds**: monthly climatology based on ECMWF reanalysis

The main differences in this phase are:

- resolution
- domain (& boundary conditions)
- numerics/physics

Data access and management

An AOMIP-LAS (Live Access Server) has been created. The AOMIP common-forcing data sets, archived at the AOMIP website, are available through the AOMIP-LAS. The model results from each AOMIP group are stored on a group's home-institute website but are directly accessible to all through the AOMIP-LAS. Results are interpolated on a common (relatively low resolution) grid. The possibility of sharing AOMIP model data through the Joint Office for Science Support (JOSS) is currently being investigated. As a data format – NetCDF has been adopted as the AOMIP standard for data format and exchange.

9. JOINT SESSION WITH ATLANTIC PANEL

WGOMD and the CLIVAR Atlantic Panel held a joint session during their recent meetings. The participants were welcomed by the chairmen of both groups, Martin Visbeck (Atlantic) and Claus Böning (WGOMD) who gave introductions about the tasks of the individual panels.
It was emphasised that the aim was to exchange information about the working areas and interest, specifically the Atlantic panel was asked to provide inputs on metrics and indices of climate variability in the Atlantic sector to be used for model-model and model-data intercomparison studies. The Atlantic panel expressed interest to access output from model experiments (e.g. OMIP) for intercomparison with observations. The initial focus was to identify jointly a metric and develop model experiments to explore the responses and sensitivity of the Meridional Overturning Circulation (MOC).

9.1 Summary of OMIP status and plans

A.-M. Treguier gave a short progress report on the P-OMIP (Pilot Ocean Model Intercomparison Project) study. The goal of the P-OMIP is to demonstrate the feasibility and merit of a coordinated investigation of global ocean-ice model performance. WGOMD has formulated and agreed on a protocol, (basically following the example of a previous German 'mini-OMIP' (between two ocean models: MOM and HOPE)); it would involve a 100-year integration period and forcing by a global flux dataset based on refined ECMWF re-analysis products.

During the past year, a Pilot study with 6 participating modelling groups took place. 3 groups followed the protocol strictly, 3 with some modifications. Since a number of experiments have been completed very recently, some more analysis of the results is still required. Because of some incompatibilities, e.g. with the surface flux formulations in various coupled systems, not all groups applied the forcing protocol strictly. It was decided that some modest, but well documented modifications to the protocol should be allowed in order to allow sufficient participation. For a full OMIP additional resources would be required to perform common analysis. Potential options, including funding have to be explored.

As WGCM (Working Group on Coupled Modelling) recommended the OMIP study will be coordinated with activities within CMIP and AMIP in preparation for the next assessment of the IPCC. This means that the demonstration phase of OMIP has to be completed by early 2004. The results of this first OMIP phase should be assessed and reviewed during a workshop planned back-to-back to the next meeting of WGOMD in Spring 2004.

9.2 Summary of CMIP THC response studies ('water hosing exps.')

S. Griffies gave an overview on this subproject of the Coupled Model Intercomparison Project (CMIP). The aim is to establish a benchmark for the sensitivity of the Thermohaline Circulation (THC) to an imposed surface freshwater flux. The motivation is the broad spread of MOC scenarios as highlighted in the IPCC TAR 2001. The design is to apply a surface flux of 0.1 Sv in total, uniformly distributed over the Atlantic between 50ºN and 70ºN, for a period of 100 years, starting from a control state. This additional flux is a net addition of freshwater to the ocean; it is not compensated for by removal elsewhere. After 100 years, the imposed water flux will be switched off, and the experiment continued to run, so that any recovery can also be investigated.

Experiments like the 'water hosing' experiment of CMIP are difficult to conduct with ocean-only models. The usual restoring boundary condition on surface salinity overly damps the salinity anomaly and misrepresents the sensitivity of the oceanic circulation. Flux boundary conditions for salinity seem a more natural choice. Combined with restoring conditions for SST mixed boundary conditions are realized. This is the case whenever SST is relaxed to a fixed reference temperature, for instance by using bulk formulas for the latent and sensible heat fluxes where a prescribed air temperature enters. Mixed boundary conditions are known to result in a much too sensitive system where small changes in salinity result in massive changes in the thermohaline circulation (Bryan, 1986; Rahmstorf, 1995; Lohmann et al., 1996). The sensitivity results from the positive salinity advection feedback: Warm and saline water that is carried northward by the thermohaline circulation is cooled in high latitudes, leading to enhanced sinking. The replacement of the sinking water strengthens the thermohaline circulation. In the climate system, the negative temperature advection feedback counteracts the salinity advection feedback. The heat released by the ocean warms the atmosphere and reduces the density gain in the poleward branch of the thermohaline circulation. This feedback is suppressed with prescribed air temperatures in ocean models. Simple atmospheric models have been used to overcome these difficulties (e.g. Rahmstorf, 1995; Lohmann et al., 1996) but are no option for experiments which aim at a close simulation of the observed ocean state and its temporal development. The suggestion of splitting the salinity in two components where one is restored to reference surface salinities while the other integrates the anomalous surface fluxes is under investigation.

9.3 Data sets for testing models, particularly with respect to the THC

The MOC is believed to be the most important aspect of NA ocean circulation for climate variability. At the last Atlantic panel meeting (Bermuda July 2002), Dr. Wright was charged with the task of compiling a list of MOC observables to be passed to the ocean modelling community (WGOMD) including

- those that help to assess the model representation of processes believed to be critical for the dynamics of MOC variability
- observed decadal-interdecadal changes in quantities that are influenced by the MOC
- ongoing or planned observations that may allow quantitative assessments of the present state and future changes in the MOC

Dr. Wright began his presentation by emphasizing that the NA cannot be decoupled from the Arctic and that the THC cannot be decoupled from the wind-driven circulation. He assumed that the ocean models will be run with specified forcing from reanalysis products so that the models at least have a chance to reproduce the observations. Mean properties, statistics of variability and qualitative behaviour should also be reproduced by coupled models but they should not generally be expected to reproduce specific events.

Although the primary interest is in observations that will test the variability seen in models, the "mean" state strongly influences this variability. A model that has reasonable variability but has an incorrect base state cannot be trusted outside of the range of conditions over which it has been tested. Major pathways and mean transport estimates have been identified based on an eclectic data set that includes:

- Current meter moorings
- Cable data
- Drifters (shallow and deep)
- Hydrography and Tracers
    - Point snapshots and time series
    - Detailed correlation analyses
    - Diagnostic Calculations
    - Inverse Calculations

Recent work on data assimilative models promises both new results and estimates of uncertainties.

Direct observations of MOC variability are very limited and there is considerable uncertainty about how the observations that are available should be compared to model results. Observations of the effects of MOC variations may have to be used in lieu of direct observations in order to provide meaningful comparisons with model results. The final 'shopping-list' that Wright came up with to intercompare ocean models with observations had the following elements:

- The mean overturning circulation
- Basin scale changes in water mass properties
- Spatial and temporal variation of tracers

- Variations in sea ice and relation to SST
- Variations in SST
- Variations in major gyre transports (Curry and McCartney)
- Variations in upper ocean shelf-slope transports (analogues to Curry and McCartney)
- Variations in Florida Current transport
- Variation in transport through A5/AR1 section (24°N)
- Variations in transport through A2/AR19 section (Grand Bank to England)
- Qualitative and quantitative response to the Great Salinity Anomaly(ies)
- Production and drainage of Labrador Sea Water and deeper water masses
- "Drainage" of Greenland Sea deep water

He noted that it might also be possible to derive useful information from long-term sea level observations by looking for long-term basin-scale changes in the east-west and north-south tilts, but it is not clear whether or not a reliable estimate of variations can be extracted from the available observations. Additional items that were identified as desirable were sections across 10°N (MOVE/GAGE), 10°S, 30°S. He noted that his list of available observations was biased towards the North Atlantic and that this was partly due to less information being available for the South Atlantic but also reflected his limited knowledge of South Atlantic studies. He will be requesting input from other panel members to help fill some of the gaps.

He concluded that there is a need to discuss what observations should be compared with what models and what should be expected from the models. The webpage: http://www.clivar.org/organization/atlantic/IMPL/index.htm was mentioned as an outstanding example for the present observational database and future projects in CLIVAR Atlantic. With respect to the Tropical Atlantic variability (TAV) a new website is available under http://www.knmi.nl/~hazelege/tameet/tameetmod.html for intercomparisons with model results for tropical Atlantic circulation. This website provides links to data from ocean models that will participate in a "low profile" model intercomparison for tropical Atlantic circulation as decided during the meeting in August 2002 in Kiel. The focus will be on robust features in the models despite their differences in configuration. Especially the seasonal cycle of the different current branches is of interest. In addition the data will be used for comparison with hydrographic data.

It was agreed to foster the cooperation between the Atlantic Panel and WGOMD in the field of model and data intercomparisons. While in the present phase of OMIP it will not be possible to provide all the products being envisaged by the observational community, it was found important to explore possibilities for designing a programme of coordinated model experiments (e.g. an OMIP-2 phase) focusing on ocean variability.

Action item: Encourage joint activities on model-data intercomparison with WGOMD (*Boening, Sutton and Schott)*

At last Atlantic meeting T. Delworth was asked to lead a subgroup formed by Atlantic panel members that provide inputs to WGOMD on metrics and indices of climate variability in the Atlantic sector for model-model and model-data intercomparison studies and detection of climate change. The initial focus is on the MOC and basin-scale water mass properties as the most important oceanic features. The purposes of the model experiments are:

- Investigate the mechanism responsible for MOC variability and MOC response to forced changes, including issues of MOC stability, in a variety of (coupled and uncoupled) models

- Evaluate the extent to which MOC behaviour in a variety of models is likely to be realistic/unrealistic
- Identify key model requirements for realistic/adequate simulation of MOC variability and change (the appropriate definition of "realistic/adequate" will depend on specific purpose)
- Identify the degree to which variability in water mass properties are consistent between different models and how this variability compares with that seen in reality

A draft of primary and secondary metrics have been proposed:

Primary Metrics	**Ocean-only Models with Climatological Forcing**	**Ocean-only Models with (preferably) Identical Interannual Forcing**	**Coupled Models**
1) MOC at 26.5N (potentially also 30S, 10S, 10N, 48N)	YES (time-mean only)	YES (time-mean and time series)	YES (time-mean and time series)
2) Heat and freshwater transports as a function of latitude and time (monthly resolution)	YES (climatological seasonal cycle)	YES (climatological seasonal cycle and interannual variations)	YES (climatological seasonal cycle and interannual variations)
3) Curry and McCartney baroclinic transport index (store integrated potential energy anomalies separately)	YES (time-mean only)	YES (time-mean and time series)	YES (time-mean and time series)
4) SST gradient between North and South Atlantic	MAYBE, but caution is warranted if there is any SST restoring	YES (time-mean and time series; caution if there is SST restoring)	YES (time-mean and time series)
5) Heat and freshwater transports through key passages: a) Canadian Archipelago (if resolved), b) Iceland-Faroer-Scotland, c) Denmark Strait and d) Florida Strait	YES (time-mean only)	YES (time-mean and time series)	YES (time-mean and time series)
6) Model analogue for Bermuda hydrographic time series	NO	YES	YES

Secondary Metrics	**Ocean-only Models with Climatological Forcing**	**Ocean-only Models with (preferably) Identical Interannual Forcing**	**Coupled Models**
1) Heat and freshwater transports through additional key passages, such as Gibraltar	YES (time-mean only)	YES (time-mean and time series)	YES (time-mean and time series)
2) Upstream "heat" or deep Greenland Sea waters overflowing the Iceland-Faroer-Scotland sills	YES (climatological seasonal cycle)	YES (climatological seasonal cycle and interannual variations)	YES (climatological seasonal cycle and interannual variations)
3) T, S, and volume of Labrador Sea water	YES (time-mean only)	YES (time-mean and time series)	YES (time-mean and time series)
4) Measure of Gulf Stream	YES (time-mean	YES (time-mean and	YES (time-mean

position	only)	time series)	and time series)

Potential model experiments proposed:
a. Sensitivity to horizontal resolution of processes relevant for MOC variability and change. One such experiment could focus on the dependence on resolution of signal propagation along the western boundary. The first task is to agree on an experimental design that could sensibly be applied with a range of models.
b. Adjustment of models to surface perturbations. One such experiment is already underway; there is an existing CMIP project to examine the response of coupled models to imposed freshwater forcings, and to CO_2 increases. Another potential experiment be the response of models to perturbations associated with stronger or weaker NAO states, or to altered NAO spatial structures.

9.4 CLIVAR Workshop on North Atlantic Thermohaline Circulation Variability

A workshop on 'North Atlantic Thermohaline Circulation Variability' which will be held 13-16 September 2004 in Kiel Germany is organized under the auspices of the International CLIVAR Project by the Atlantic Implementation Panel, the Working Group on Ocean Model Development, and the Special Research Programme on the "Dynamics of Thermohaline Circulation Variability" (SFB 460) at the Institute for Marine Research (IfM) of Kiel University.
The organising committee is co-chaired by Claus Böning (Institut für Meereskunde, Kiel, Germany) and Martin Visbeck (Lamont-Doherty Earth Observatory, Palisades, USA).
The workshop intends to bring together expertise from observations, theory and modelling, to discuss recent advances and outstanding problems in our understanding of the mechanisms of deep water formation and circulation in the subpolar North Atlantic, their relation to large-scale thermohaline circulation variability and impact on the uptake anthropogenic trace gases.
Its aims are two fold: (1) To take stock of our understanding and best estimates of the present and future state of the Atlantic Thermohaline Circulation, and (2) To guide implementation plans by assessing the capabilities and future needs of THC observing and synthesis systems to detect low-frequency changes or trends.

Particular themes are:

1. What is known about the key processes governing NADW formation and its variability?
2. What are the main characteristics and mechanisms of interannual, decadal, and interdecadal variability in water mass formation, deep current systems, ocean-atmosphere fluxes, and large-scale transports?
3. What is the effect of this variability on the sequestration of anthropogenic trace gases?
4. How well are the observed behaviours captured in present ocean and climate models, and what are the main requirements for improvements?
5. What are the elements of an efficient observation system for the Atlantic THC, what are the research needs to improve its design?

Further details will be distributed at a later stage
(see http://www.ifm.uni-kiel.de/allgemein/news/nawshp_04.htm for details)
During the discussion it was suggested to include an atmospheric topic, e.g. Interaction of NAO and THC variability in the list of themes.
Action item: Update the proposal of the THC workshop and ask SSG for endorsement. (*Visbeck, Boening and Boscolo*)

9.5 CLIVAR Conference

The co-chair of the CLIVAR Scientific Steering Group A. Busalacchi gave an overview about the scope and format of the first international CLIVAR Science Conference, to be held, 21-25 June, 2004 in Baltimore, USA. The conference will review the first phase of CLIVAR and feature

- Overviews prepared by expert teams
- Invited presentations and discussion forums

- Contributed poster presentations (with special emphasis on young scientists' participation).

Contributions are solicited on research topics will include, but not be limited to:

- **Advances in understanding elements of the climate system**
  Seasonal-to-interannual variability especially ENSO, monsoon systems, decadal (and longer) variability, and anthropogenic climate change
- **Looking into the past**
  Analysis of paleoclimate records; reanalyses
- **New approaches to climate prediction**
  Modelling, data assimilation, and validation
- **Improvements to the observing system**
- **Climate applications**
  Who are our clients? What products and Information do they need?

Consult the conference web site (http://www.clivar2004.org) for more details.

The preliminary programme is almost complete and will be released shortly. Busalacchi recommended to the panels to work together with the designated speakers on the preparation of the presentations. It is envisaged to prepare a special issue of the main conference papers in Journal of Climate.

10. FUTURE ACTIVITIES

10.1 Workshop on Ocean Climate Modelling

WGOMD decided to organize a scientific workshop back-to back to the next meeting in spring 2004. Building on the results of the first phase of OMIP, the meeting will assess the state of ocean models for climate studies, and for other activities in the context of CLIVAR (e.g. for assimilation, process studies, etc.). The focus will be on specific critical processes and themes. A preliminary list of such processes and themes, including encompass**:**

- Ice-ocean interaction and deep water formation in the Southern Ocean
- Ventilation of the thermocline
- Deep convection in the northern North Atlantic and its link to overturning
- Gravity currents and entrainment
- Eddy parameterization

In preparation for the workshop, various groups expressed interest in performing analysis of OMIP output, aiming at the representation of these key processes and phenomena in comparison to observed behaviours and insight from process studies.

The size of this meeting should be around 30-40 people. Some participation from the observational community is envisaged to facilitate intercomparisons between model results and data. A subgroup, chaired by S. Griffies has been asked to define the scientific programme in more detail. T. Hirst (CSIRO) has volunteered to host this meeting in Hobart in early March 2004.

WGOMD asks the CLIVAR SSG and WGCM to endorse the idea of such a workshop.

Action item: Ask the CLIVAR SSG to endorse this activity (C. Boening to SSG); T. Hirst to explore options for the venue; S. Griffies, T. Hirst and other WG members to work on the scientific programme.

11. OTHER BUISINESS

11.1 Membership

At present the membership of WGOMD is:

C. Böning (Chair)	Institut für Meereskunde, Kiel, Germany
F. Bryan	National Center for Atmospheric Research, Boulder, USA
E. Chassignet	RSMAS, Miami, USA.
R. Gerdes	Alfred-Wegener-Institut für Polar und Meeresforschung, Bremerhaven, Germany
S. Griffies	Geophysical Fluid Dynamics Lab., NOAA, Princeton, USA
H. Hasumi	Center for Climate System Research, Tokyo, Japan
A. Hirst	CSIRO, Aspendale, Australia
A.-M. Treguier	IFREMER, Brest, France
D. Webb	Southampton Oceanography Centre, Southampton, UK

The WG discussed ways to begin rotating membership. For 2004 two members were nominated to rotate off, two successors were nominated. In addition, it was proposed to extent the group by one person.. The details will be reported to the CLIVAR SSG and WGCM for endorsement.

(**Action item: Inform CLIVAR SSG and WGCM: Böning**)

Appendix A: List of participants

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Appendix B: Agenda

1. MEETING ORGANIZATION

- Meeting arrangements (*Villwock, Boening*)
- Review of agenda (*Boening*)

2. REVIEW OF WCRP AND RELATED ACTIVITES

- Reports and requests from JSC, CLIVAR SSG, WGCM (*Cattle, Villwock, Boening*)
- Developments in ACSYS/CliC (*Beckmann*)

3. REVIEW OF OCEAN MODEL DEVELOPMENTS

- Brief reports on the status of ocean models used for climate studies, and of new model developments (GFDL, NCAR, Hadley Centre, MPI, CSIRO, Earth Simulator, other)

4. OCEAN REANALYSIS & DATA ASSIMILATION (*Stammer*) – Jointly with the Atlantic Panel

5. PILOT OCEAN MODEL INTERCOMPARISON PROJECT (P-OMIP) (*Treguier*)

- Status reports from POMIP groups
- Review of atmospheric forcing choices (*Roeske*)
- Diagnostic sub-projects
- Discussion of merits and feasibility
- OMIP protocol refinements
- Logistics
- Public announcement
- Diagnostic sub-projects

6. CMIP EXPERIMENTS ON THE ATLANTIC THC RESPONSE

- Coordinated coupled model experiments on the response of the THC to surface forcing anomalies (*Griffies*)
- Discussion of merit and possibilities of coordinated ocean-only (OMIP) experiments on the response to specified flux anomalies

7. OCEAN MIXING

- The US Climate Process Team on Ocean Mixing (*Large*)
- Discussion of possible WGOMD initiatives (e.g., workshop)

8. POLAR OCEANS

- AOMIP developments (*Gerdes*) & discussion of AOMIP-OMIP liaison

9. JOINT SESSION WITH ATLANTIC PANEL

- Introductory remarks about the tasks and activities of the Atlantic Panel (*Visbeck*)
- Same for WGOMD (*Boening*)
- Review of Atlantic modelling issues (i.e. can models guide obs. systems despite the existing sensitivities?) (all)
- Summary of OMIP status and plans (*Treguier*)
- Data sets for testing models, particularly with respect to the THC (*Wright*)
- Summary of CMIP THC response studies ('water hosing exps.') (*Griffies*)
- Update on the proposal of a CLIVAR Workshop on THC variability (*Boening*)

10. FUTURE ACTIVITIES

- Workshop on Ocean Climate Modelling
    - Do we need a workshop?
    - Themes
    - Organization

Adjourn general meeting

12. OTHER BUISINESS

- Membership
- Future activities
- Upcoming other panel meetings
- Next WGOMD meeting