# Ocean Modelling Activities in Canada

## Report to the CLIVAR Working Group for Ocean Model Development

**Submitted by Richard Greatbatch, July 2007**

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

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

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

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

**(i) Mike Foreman:**

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

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

**(iii) Rick Thomson and Scott Tinis:**

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

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

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

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

Our group has focused a lot of attention recently on the carbon cycle. We have developed (along with Andreas Schmittner at OSU) a comprehensive carbon cycle-climate model. The ocean component includes an NPZD ocean biology model and the required additional ocean chemistry. An ocean sediment model has also just been added. These models coupled to the rest of the UVic Earth System Climate Model allow long term climate simulations with carbon as a completely prognostic variable. Many experiments have already been carried out including the assessment of the long term fate of anthropogenic CO2, the effect of changing Southern Ocean winds on carbon uptake and the carbon cycle response to a collapse of the Atlantic overturning circulation.

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

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

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

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

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

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

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

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

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

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

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

### (i) Charles Hannah:

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

### (ii) Dan Wright:

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

### (iii) Frederic Dupont:

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

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

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

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

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

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

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

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

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

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

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

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