Ocean General Circulation Development in the Scandinavian Countries (Denmark, Norway, Sweden), 2007

by
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with input from

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1. DENMARK

1.1 Danish Meteorological Institute, DMI

No input yet – vacation time...

2. SWEDEN

2.1 Swedish Meteorological and Hydrological Institute, SMHI

At the Swedish Meteorological and Hydrological Institute (SMHI), ocean modelling is done for climate studies, physical and biogeochemical process studies and for operational forecasts. Modelling projects are focusing on the Arctic, the Baltic Sea and global studies.

Model systems in use are the Rossby Centre regional ocean model RCO[1] (derived from OCCAM), the global coupled model CCSM3 including ocean component and the operational ocean model HIROMB (High Resolution Operational Model for the Baltic Sea[2]). During fall 2007, the ocean model NEMO (OPA) will be adopted for a global domain, later also in the regional domains.

Current and near future modeling activities are:

- Coupled ocean-ice-atmosphere runs for a regional Baltic Sea domain in 6 nautical miles (nm) and 2 nm resolution, using RCO ocean, coupled by OASIS4.
- Coupled physical-biogeochemical runs for the Baltic Sea using RCO-SCOBI (2 and 6 nm resolution) for 100-year long simulations (hindcasts and scenarios).

[1] http://www.smhi.se/sgn0106/if/rc/rco.htm
[2] http://www.smhi.se/oceanografi/oce_info_data/models/hiromb.htm

- Regional Arctic coupled ocean-ice-atmosphere process studies, predictability studies and climate scenarios, using RCO ocean model in 0.5 and 0.25 degrees resolution.
- Regional Arctic ocean-ice process studies on interdecadal variability and biogeochemical processes, using RCO ocean model in 0.5 and 0.25 degrees (or better), for 100-year long simulations (with new sea-ice module).
- Global coupled ocean-ice atmosphere climate runs, using NEMO (OPA)
- High resolution Baltic Sea runs using RCO-SCOBI with at least 1 nm resolution (25-year long simulations)

A list of recent publications based on SMHIs OGCM-system(s):

Döös, K., Meier, H. E. M. and Döscher, R. 2004. The Baltic Haline Conveyor Belt or The Overturning Circulation and Mixing in the Baltic. Ambio 33:4-5, 257-260.

Döscher, R. and Meier, H. E. M. 2004. Simulated Sea Surface Temperature and Heat Fluxes in Different Climates of the Baltic Sea. Ambio 33:4-5, 242-248.

Kjellström, E., Döscher, R. and Meier, H. E. M. 2005. Atmospheric response to different sea surface temperatures in the Baltic Sea: Coupled versus uncoupled regional climate model experiments. Nordic Hydrology 36:4-5, 397-409.

Meier, H. E. M. 2005. Modeling the age of Baltic Seawater masses: Quantification and steady state sensitivity experiments. J. Geophys. Res. 110, C02006, doi:10.1029/2004JC002607.

Meier, H. E. M. 2005. The doubly stratified regime: turbulence closures for an OGCM of the Baltic Sea. In: H. Z. Baumert, J. Simpson, and J. Sündermann (eds.), Marine Turbulence: Theories, Observations, and Models. Results of the CARTUM Project, chapter 47, Cambridge University Press, Cambridge, 376-382.

Meier, H. E. M. 2006. Baltic Sea climate in the late twenty-first century: a dynamical donwscaling approach using two global models and two emission scenarios. Clim. Dyn. 27, 39-68, doi:10.1007/s00382-006-0124-x.

Meier, H. E. M., Broman, B. and Kjellström, E. 2004. Simulated sea level in past and future climates of the Baltic Sea. Clim. Res. 27, 59-75.

Meier, H. E. M., Broman, B., Kallio, H. and Kjellström, E. 2006. Projections of future surface winds, sea levels, and wind waves in the late 21st Century and their application for impact studies of flood prone areas in the Baltic Sea region. In: Schmidt-Thomé, P. (ed): Sea level change affecting the spatial development of the Baltic Sea region, Geological Survey of Finland, Special Paper 41, 23-43.

Meier, H. E. M., Döscher, R. and Halkka, A. 2004. Simulated Distributions of Baltic Sea-ice in Warming Climate and Consequences for the Winter Habitat of the Baltic Ringed Seal. Ambio 33:4-5, 249-256.

Meier, H. E. M., Döscher, R., Broman, B. and Piechura, J. 2004. The major Baltic inflow in January 2003 and preconditioning by smaller inflows in summer/autumn 2002: a model study. Oceanologia 46, 557-579.

Meier, H. E. M., Kjellström, E. and Graham L. P. 2006. Estimating uncertainties of projected Baltic Sea salinity in the late 21st century, Geophys. Res. Lett. 33, L15705, doi:10.1029/2006GL026488.

Meier, H.E.M. 2007. Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea. Estuarine, Coastal and Shelf Science, Vol. 74/4, 717-734.

Räisänen, J., Hansson, U., Ullerstig, A., Döscher, R., Graham, L. P., Jones, C., Meier, H. E. M., Samuelsson, P. and Willén, U. 2004. European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. Clim. Dyn. 22, 13-31.

3. NORWAY

The main groups working with OGCM development in Norway are located in Bergen and in Oslo, with a minor activity in Tromsø.

The following OGCMs are in use in Norway for climate studies:

1) HYCOM/MICOM (both in Bergen and in Oslo)
2) MITgcm (in Bergen and Tromsø)
3) ROMS (in Bergen)

3.1 Bergen / Bjerknes Centre for Climate Research (BCCR) (Institute for Marine Research IMR, Nansen Environmental and Remote Sensing Center NERSC, and University of Bergen UoB)

All climate related research in Bergen, students, PostDocs and scientists included, is organized under the Bjerknes Centre for Climate Research (http://www.bjerknes.uib.no). In 2007, about 30 person years are devoted to integrating, analysing and improving the OGCMs in use in Bergen.

The activity with HYCOM/MICOM is largest, representing about 80% of the total effort. 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), participating in the IPCC 4AR.

The following classes of studies are carried out:

1) Global and basin spatial scale, interannual to centennial time scale climate studies (NERSC version of MICOM and ROMS, both fully coupled to dynamic/thermodynamic sea ice modules)
2) Global and basin spatial scale, interannual to centennial time scale climate studies on ecosystem and carbon cycle (HYCOM/NERSC version of MICOM)
3) Process studies (all model systems)
4) Global climate modelling with the *Bergen Climate Model* (participating in IPCC 4AR) (NERSC version of MICOM)
5) Data assimilation (HYCOM)

3.1.1. Status 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) Global model with grid focus in the Atlantic Ocean (35 isop layers; 80 and 40 km horiz resolution in the focus region; grid poles over Europe and N America).

(ii) 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) Global version with poles over Siberia and Antarctica (35 isop layers; 1.5 cosφ (Mercator) horizontal resolution), and with enhanced meridional resolution along equator.

Model version (iii) forms the ocean component of the global coupled Bergen Climate Model (BCM). Major achievement with version (iii) has been completion of the IPCC 4AR runs without 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 reformulated
- 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 (avoiding creeping isopycnals)
- Fix to improve numerical stability (velocity limiting in barotrop and baroclinе 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

The model system has been applied to, in particular, addressing fluctuations in the marine climate of the northern North Atlantic, the Nordic Seas and the Arctic Ocean.

Recent (post 2005) publications

Bethke, I., T. Furevik, and H. Drange (2006), Towards a more saline North Atlantic and a fresher Arctic under global warming, *Geophys. Res. Lett.*, 33, L21712 [file]

Collins, M., M. Botzet, A. Carril, H. Drange, A. Jouzeau, M. Latif, O. H. Otterå, H. Pohlmann, A. Sorteberg, R. Sutton, L. Terray (2006): Interannual to decadal climate predictability: A multi-perfect-model-ensemble study. *J. Climate*, 19, 1195-1203, doi:10.1175/JCLI3654.1 [file]

Deshayes, J., C. Frankignoul, and H. Drange (2007), Formation and export of deep water in the Labrador and Irminger Seas in a GCM, *Deep Sea Research 2*, in press [file]

Drange, H., R. Gerdes, Y. Gao, M. Karcher, F. Kauker, and M. Bentsen (2005), Ocean general circulation modelling of the Nordic Seas, in *The Nordic Seas: An Integrated Perspective*, (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 199-220 [file] [book]

Drange, H., T. Dokken, T. Furevik, R. Gerdes, W. Berger, A. Nesje, A. A. Orvik, Ø. Skagseth, I. Skjelvan, and S. Østerhus (2005), The Nordic Seas: An introduction, in *The Nordic Seas: An Integrated Perspective* (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 1-10 [file] [book]

Eldevik, T. , F. Straneo, A.B. Sandø, and T. Furevik, 2005: Pathways and export of Greenland Sea Water. *The Nordic Seas: An integrated perspective*, H. Drange, T.M. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds., Geophysical Monograph Series, AGU, 89-103

Gao Y., Drange H., Bentsen M., Johannessen O.M. (2005), Tracer-derived transient time of the eastern waters in the Nordic Seas, *Tellus*, 57B, 332-340 [file]

Hátún, H., A. B. Sandø, H. Drange, B. Hansen, and H. Valdimarsson (2005), Influence of the Atlantic Subpolar Gyre on the Thermohaline Circulation, *Science*, 309, 1841-1844 [article] [info]
Hátún, H., Sandø, A. B., Drange, H. and Bentsen, M. (2005), Seasonal to decadal temperature variations in the Faroe-Shetland inflow waters, in *The Nordic Seas: An Integrated Perspective*, (Drange, H., T. Dokken, T. Furevik, R. Gerdes, and W. Berger, Eds.), AGU Monograph 158, American Geophysical Union, Washington DC, 239-250 [file] [book]
Kuzmina, S. I., L. Bengtsson, O. M. Johannessen, H. Drange, L. P. Bobylev and M. W. Miles (2005): The North Atlantic Oscillation and greenhouse-gas forcing, *Geophys. Res. Lett.*, 32, L04703, doi:10.1029/2004GL021064 [file]
Mauritzen, C., Hjøllo, S. and Sandø, A. B. (2006). Passive tracers and active dynamics - a model study of hydrography and circulation in the northern North Atlantic, *J. Geoph. Res.*, 111 , C08014, doi:10.1029/2005JC003252 [article]
Orre, S., Y. Gao, H. Drange, and E. Deleersnijder (2006), Transport and time scales associated with idealized trasers released in the North-East Atlantic, *Eust., Coastal Shelf Sci.*, in revision
Orre, S., Y. Gao, H. Drange, and J. E. Ø. Nilsen (2006), A reassessment of the dispersion of Technetium-99 in the North Sea and the Norwegian Sea, *J. Mar. Sys.*, doi:10.1016/j.marsys.2006.10.009 [file]
Risebrobakken, B., Dokken T., Otterå O. H., Jansen E., Y. Gao, H. Drange (2006), Inception of the northern European ice sheet due to contrasting ocean and insolation forcing, *Quaternary Research*, 667, 128-135, doi:10.1016/j.yqres.2006.07.007 [file]
Siegismund, F., J. Johannessen, H. Drange, K. A. Mork, A. Korablev (2007), Steric height variability in the Nordic Seas *J. Geophys. Res.*, accepted [file]
Sorteberg, A., T. Furevik, H. Drange, and N. G. Kvamstø (2005), Effects of simulated natural variability on Arctic temperature projections, *Geophys. Res. Lett.*, 32, L18708, doi:10.1029/2005GL023404. [file]
Su, J., H.-J. Wang, H. Yang, H. Drange, Y. Gao, and M. Bentsen (2007), Role of the atmospheric and oceanic circulation in the tropical Pacific SST changes, *J. Clim.*, accepted
Vikebø F, Sundby S, Ådlandsvik B, Otterå OH (2007) Impacts of a reduced THC on transport and growth of Arcto-Norwegian cod, *Fisheries Oceanography*, 16 , No. 3, 216-228
Zhou, T. J., and Drange H. (2005), Climate Impacts of the Decadal and Interannual Variability of the Atlantic Thermohaline Circulation in Bergen Climate Model, *Chinese J. Atm. Sci.*, 29, 167-177 (Chinese journal with English abstract) [file]

3.1.2 Development of a new layered 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.

Test versions of the new OGCM are being tested (2007). The OGCM is also coupled to

the ocean biogeochemistry model HAMOCC5.1 from the Max-Plank Institute for Meteorology in Hamburg, leading to a new isopycnic ocean carbon cycle model.

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)

3.1.3 Status 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:

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.

Budgell, W.P., 2005, Numerical simulation of ice-ocean variability in the Barents Sea region: Towards dynamical downscaling, Ocean Dynamics, DOI 0.1007/s10236-005-0008-3.

Lien, V., W.P. Budgell, B. Ådlandsvik and E. Svendsen, 2005, Volume transports and heat fluxes in the Nordic Seas. Results from ROMS (Regional Ocean Modelling System). Draft manuscript.

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.

3.2 Status Oslo Regional Climate Model (ORCM) (Lars Petter Rød/Jens Debernard)

In Oslo, 4-5 persons work on ocean climate modelling.

ORCM 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

Debernard, J., et al., 2003: Improvements in the sea-ice module of the regional coupled atmosphere-ice-ocean model and the strategy and method for the coupling of the three spheres. *In: RegClim Tech. Rep. No. 7*, Eds. T. Iversen and M. Lystad, 59-70. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

Røed, L. P. And J. Debernard, 2004: Description of an integrated flux and sea-ice model suitable for coupling to an ocean and atmosphere model. *met.no Report No. 4*. ISSN 1503-8025.

Røed, L. P., and J. Debernard, 2005: Simulations with a North Atlantic coupled ice-ocean model. *In: RegClim Tech. Rep. No. 8*, Eds. T. Iversen and M. Lystad, 69-81. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

Debernard, J., and M. Ø. Køltzow, 2005: Technical documentation of Oslo Regional Climate Model, Version 1.0, *In: RegClim Tech. Rep. No. 8*, Eds. T. Iversen and M. Lystad, 51-68. [Available from the Norwegian Meteorological Institute, P.O. Box 43 Blindern, 0313 Oslo, Norway]

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