# The ocean component of the Norwegian Earth System Model

Mats Bentsen<sup>1,2</sup>, Helge Drange<sup>3,2</sup>, Ingo Bethke<sup>1,2</sup>

<sup>1</sup>Uni Bjerknes Centre <sup>2</sup>Bjerknes Centre for Climate Research <sup>3</sup>University of Bergen

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### The NorESM ocean component

- Based on Miami Isopycnal Coordinate Ocean Model (MICOM).
- Further developed at the Nansen Center and now the Uni Bjerknes Centre.
- Earlier version used as ocean component of the Bergen Climate Model (BCM).
- NorESM is based on the Community Climate System Model version 4 (CCSM4) and differs in the ocean component, ocean carbon cycle, and the treatment of atmospheric chemistry, aerosols, and clouds.
- Application of the CORE forcing is available trough the CCSM4 framework.



#### Handling of tracers

- Tracer and age-tracer implemented in a modularized, resonable accurate, consistent, and efficient manner.
- Incremental remapping (Dukowicz and Baumgardner, 2000) is used for the tracer advection.
- Important step for including carbon cycle component and other tracer studies.

Backward trajectory method:





Fluxing area for C-grid



#### Pressure gradient force and conservation

- A new formulation of the pressure gradient force (Janjić, 1977; Bleck, pers. comm.) allows the use of a more accurate equation of state and  $\sigma_2$  as vertical coordinate.
- Accompanied by a modified barotropic/baroclinic mode splitting.
- Improved conservation.
- Facilitates mass flux through the ocean surface.
- Simplifies the inclusion of ice sheets.

Finite difference representation of  $-\nabla_p \Phi$ 



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Conservation of heat and salt seems good enough for long climate simulations. Global mean temperature (right) and salinity (left) from pre-industrial spinup.





#### Further numerical/technical developments

- Hybrid MPI/OpenMP parallelized (borrowed from HYCOM).
- Can be configured on tripolar grids (borrowed from HYCOM).
- The I/O functionality has been rewritten and the diagnostic capability extended to meet the requirements of CMIP5.
- Further modified barotropic/baroclinic mode splitting to improve numeric stability (Morel et al., 2008). This led to a doubling of the allowable baroclinic time-step.
- A robust implicit method for diapycnal mixing has been implemented. The method is based on Hallberg (2000).
- The Hamburg Ocean Carbon Cycle (HAMOCC) model has been added.



## Main motivations for further modifications and parameterizations

- Unrealistic representation of the Southern Ocean.
- Cold bias in the tropical Pacific.





Southern Ocean sea ice area is severely underestimated the first decades followed by a gradual buildup with too much multiyear ice.



#### Potential temperature in the Atlantic sector of the Southern Ocean



- The whole water column of Southern Ocean gets cooled down
- One of the major deficiencies of BCM and other global MICOM applications



Difference between sea surface temperature in present day coupled experiment and Levitus climatology.



sst diff. NPD off 2-Levitus 12-21 yr

Cold bias in tropical Pacific.



#### Parameterization of mixed layer depth

- Replaced the TKE balance of Gaspar (1988) with that of Oberhuber (1993).
- Extended the Oberhuber (1993) scheme with a parameterization of mixed layer restratification by eddies (Fox-Kemper et al., 2008).



y (km)



#### Treatment of near surface stability

 Using σ<sub>2</sub> as vertical coordinate has the potential for realistic mixing and transport in many regions of the world ocean (McDougall and Jackett, 2005), but the choice is not without drawbacks.



Profile of potential densities in the Weddell Sea with temperature and salinity from Levitus climatology. Reference pressures are:

- 0 db for blue line
- 1000 db for green line
- 2000 db for red line



Static stability at the base of the mixed layer base and the quasi-isopycnic layer is determined with in situ density.



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#### Mixed layer depth comparison (10 year average)



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### Thickness and isopycnal eddy diffusion

- Thickness diffusion as in Gent and McWilliams (1990) is implemented as layer interface diffusion.
- The parameterization of thickness diffusivity by Eden and Greatbatch (2008) has been implemented.
- The diffusivity is expressed as  $K=cL^2\sigma$  where  $L=min(L_{Rhi}, L_r)$ ,  $L_{Rhi}$  is the Rhines scale,  $L_r$  is the Rossby radius,  $\sigma$  is the Eady growth rate, and c is a tunable parameter.
- Motivated by Eden et al. (2009), isopycnal tracer diffusivity is set equal thickness diffusivity.
- Thickness and isopycnal eddy tracer/momentum diffusion are reduced when the first baroclinic Rossby radius is resolved by the grid (pers. comm. Hallberg). Momentum diffusion is also reduced accordingly.





Annual mean diffusivity at 300 m.







## Further improvements to get the Southern Ocean right

- Added a surface layer with constant thickness (10 m). This layer is always contained in the mixed layer and the vertical mixing between the two layers in the mixed layer follows a simplified KPP (Large et al., 1994) parameterization.
- Salt released during freezing of sea-ice can be distributed below the mixed layer. This also means that the contribution to turbulent kinetic energy generation in the mixed layer by brine release is reduced, leading to more realistic mixed layer depths below sea-ice.



#### Improved Southern Ocean hydrography



Initial condition (Levitus)

Figures show temperature in a meridional section of the Atlantic part of the Southern Ocean. The NorESM results (lower panels) are after 50 years of simulation.

The model can now better maintain the warm subsurface layer in the Southern Ocean. Still too much deep water formed.



NorESM new

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## Diapycnal mixing

- Background mixing is either constant or scales with 1/*N*.
- Includes shear driven mixing dependent on local gradient Richardson number. The maximum allowable mixing due to shear instability is greatly increased near the bottom to provide sufficient mixing downstream of overflows.
- Added bottom boundary mixing by assuming that a part of the energy extracted from the mean flow by the bottom drag drives diapycnal mixing (Legg et al., 2006).
- Added as an option a parameterization of tidally driven mixing by Simmons et al. (2004) and Jayne (2009).
- Added as an option latitude dependent diapycnal background diffusivity close to the formulation by Gregg et al. (2003).



Annual mean diapycnal diffusivity of the pre-industrial spinup in a Pacific section (130 W).



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The cold bias in the tropical Pacific has been greatly reduced. In this model this was achieved by:

- Latitude dependent background mixing.
- Reduction of thickness and isopycnal mixing when the first baroclinic Rossby radius is resolved by the grid.



Note: the experiment shown to the right has also modified parameters for the Eden and Greatbach (2008) eddy mixing parameterization.



#### Atlantic meridional overturning circulation



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Sea surface salinity difference from climatology (left) and barotropic stream function in years 15-17 of pre-industrial spinup.





Maximum AMOC strength in

- Baseline pre-industrial experiment (blue).
- With global SSS relaxation towards climatology (red).
- With SSS relaxation in Arctic only (magenta).
- Salt rejected during ice formation is discarded (cyan).









#### Evolution of heat content

Average net top of atmosphere radiation for the last 100 years of the spinup is +0.061 W/m2.





#### Sea surface temperature





#### **Evolution of salt**





#### Sea surface salinity





#### Sea-ice extent





#### NINO3.4 index





Net TOA radiation (positive downward).











Global MOC NAER1850CNOC\_f19\_g16\_04 560-590yr



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Barotopic streamfunction NAER1850CNOC\_f19\_g16\_04 560-590yr







