**NorESM**

The Norwegian Earth System Model (NorESM) version 1 is based on the Community Earth System Model version 1.0 (CESM1.0) featuring atmospheric chemistry by Oslo University, Norway and Miami Isopycnic Coordinate Ocean Model (MICOM) by Uni Research Ltd., Bergen, Norway. The model differences with the observations (WOA09) reveal a dipole PD anomaly bias in the ocean simulation, where surface salinity restoring has been applied. The surface potential density in the Control run and WOA09 observations and surface heat and fresh buoyancy forcing and evaluated them against observational estimates. Below are shown comparison of vigorous AMOC, we analyzed the processes of water mass formation as diagnosed from the surface boundary forcing. The model bias in the STMW density, but still the smaller rates. The salinity restoring in the atmosphere. MICOM and CICE are on tripole grid ~1° horizontal resolution and 53 vertical levels in the atmosphere. Eden & Greatbatch (2008) and Mixed Layer Eddy (MLE) parameterization by Fox-Kemper et al., 2008. 

**Summary**

We investigate the Atlantic Meridional Overturning Circulation (AMOC) in the Norwegian Earth System Model (NorESM) featuring isopycnal ocean component (MICOM). The Coupled Model Intercomparison Period 5 (CMIP5) NorESM ocean historical simulations showed a decline of the AMOC after 1980 concurring with the recent observations from RAPID-MOCCHA program. The NorESM future projections predict reduction of the AMOC with 12 to 30% under different warming (RCP2.6-RCP8.5) scenarios. In the CMIP5 model intercomparison project, the NorESM ocean component demonstrated an intense AMOC and took place in the upper end of the AMOC magnitudes model range. The NorESM AMOC strength was found to be sensitive to the SST response and whether coupled or uncoupled configuration is used. However, the AMOC tends to be on the strong side in all configurations. In order to find the causes of this vigorous AMOC we carried out a careful diagnostics of the AMOC and explored possible relationship to the model biases found in the Atlantic thermohaline structure, and water mass formation. Several processes has been investigated to understand further their connection and significance to the AMOC strength and variability: 1) The North Atlantic Mode Waters Formation (STMW and SPMW); 2) The Labrador Sea Water Mass formation and variability. Furthermore, the AMOC sensitivity to grid scale physical parameterizations such as isopycnal eddy mixing and the impact of model resolution on the representation of overflows is examined.

**Water Mass Formation**

To understand further the origins of the model biases in the thermohaline structure and their relation to the vigorous AMOC, we analyzed the processes of water mass formation as diagnosed from the surface boundary forcing and evaluated them against observational estimates. Below are shown comparison of the surface potential density in the Control run and WOA09 observations and surface heat and fresh water fluxes to the NQC1.1a (UK National Oceanographic Center) observational data. Besides the observed estimates we compared the results from the fully-coupled “Control” run to “CORE2” forced ocean simulation, where surface salinity restoring has been applied.

**Potential Density**

The model (Control) differences with the observations (WOA09) reveal a dipole PD anomaly bias in the Tropics which might be responsible for creating a pressure gradient and consequently intensification of the MOC. In CORE2 Experiment bias is controlled.

**Surface Heat and Fresh Water Fluxes**

According to Eden & Greatbatch (2008) and Mixed Layer Eddy (MLE) parameterization by Fox-Kemper et al., 2008. To the left are compared the Atlantic zonal mean vertical sections of temperature and salinity of the CMIP5 setup of NorESM (Control Exp) and World Ocean Atlas, 2009 (WOA09) climatologies. Some of the major biases in the model are the cool and fresh bias in the upper thermocline (500m), warm and salty bias at the surface, and in the intermediate layers 1500-2000m in North Atlantic, and cold and fresh bias in Southern Ocean. Range of the biases are for Temp. -0.3 – 0.3 °C and for Sal. -0.6 – 0.8 g/kg.

**Model Waters**

Mode waters are near surface thick layers with homogeneous physical properties usually formed during the winter convection (therefore can be located in areas with deep mixed layers) and submerging during the summer season. There are two main mode waters in North Atlantic: Sub-tropical Mode Water (STMW) and Sub-polar Mode Water (SPMW). STMW is formed in a rather lighter density classes and smaller rates. The salinity restoring in the surface boundary forcing (CORE2) seems to fix the mismatch in the STMW density, but still the model has a tendency to overestimate SPMW formation.

**Stability Stratification**

To the right are shown water mass transformation rates (WATR), as defined by Speer&Tziperman (1992). They indicate the amount of water formed in a certain density range at the surface due to the surface heat flux and fresh water (SPMW, SPMW) formation. Generally the biases in the SHF remain small rates. The salinity restoring in the atmosphere. MICOM and CICE are on tripole grid ~1° horizontal resolution and 53 vertical levels in the atmosphere. Eden & Greatbatch (2008) and Mixed Layer Eddy (MLE) parameterization by Fox-Kemper et al., 2008. They indicate the amount of water formed in a certain density range at the surface due to the surface heat flux and fresh water (SPMW, SPMW) formation. Generally the biases in the SHF remain small rates. The salinity restoring in the atmosphere. MICOM and CICE are on tripole grid ~1° horizontal resolution and 53 vertical levels in the atmosphere. Eden & Greatbatch (2008) and Mixed Layer Eddy (MLE) parameterization by Fox-Kemper et al., 2008. Some of the major biases in the model are the cool and fresh bias in the upper thermocline (500m), warm and salty bias at the surface, and in the intermediate layers 1500-2000m in North Atlantic, and cold and fresh bias in Southern Ocean. Range of the biases are for Temp. -0.3 – 0.3 °C and for Sal. -0.6 – 0.8 g/kg.

**Table 1. Description of the Numerical Experiments**

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**Overspill Waters**

In this CORE2 forced experiment we investigate the representation of the overflow in the 1° NorESM CMIP5 setup by released tracer inventory of passive tracer (thickness integration of tracer concentrations below layer 34) after 15 years of its release. From the figure we can diagnose the pathways of Denmark Strait Overflow Water (DSOW) and Iceland-Scotland Overflow Water (ISOW). The DSOW propagates all the way south to the western European Basin instead of turning westwards across Reykjanes Ridge and at the Charlie Gibbs Fracture Zone (Saunders 1994; Saunders et al. 2010). This is because the core of DSOW fails to reproduce inclined isopycnals in the Irminger Basin hence there is a lack of overflow water on the slope that is important for its cross-ridge transport. This issue, together with the underestimation of DSOW only a third of the observed), causes lack of overflow waters in the western North Atlantic in this coarse resolution version of the model.

**Sensitivity to Isopycnal Mixing**

NorESM isopycnal thickness diffusivities are generally large near the surface, the model within the western boundary currents and northward of Acic and decay with depth. In our experiments E1-E12 we have aimed to decrease the original (Control) setup of isopycnal mixing in order to reduce the biases in the thermohaline structure.

**Global Ocean Zonal Mean Vertical Distribution of the Mode Waters**

The ED2008 isopycnal thickness diffusivities. Generally they are large near the surface, the most within the western boundary currents and northward of Acic and decay with depth. In our experiments E1-E12 we have aimed to decrease the original (Control) setup of isopycnal mixing in order to reduce the biases in the thermohaline structure.

**NorESM1 has been found to be on the strong side of AMOC magnitudes among the CMIP5 models with maximum AMOC ~28-30Sv. In a forced simulation of NorESM within the CMIP5 protocol experiment the strength of the AMOC was possible to restrain to the observed ~18Sv values via sea surface salinity restoring (see below). In the present study, we explore the sensitivity of the AMOC to the 3-D isopycnal mixing parameterization in the NorESM ocean model based on Eden and Grebath (2008). By varying the parameters (- is maximum diffusion rate in the isopycnal slice) we succeeded to reduce the temperature and salinity biases locally and the AMOC magnitude by 25% (Exp. E4, see to the right: The isopycnal thickness diffusivity in the MOC region). The largest isopycnal thickness diffusivity biases were achieved by implementing a 2-D version of the parameterization that reduced the biases in the entire water column.

**NorESM2**

The model (Control) differences with the observations (WOA09) reveal a dipole PD anomaly bias in the Tropics which might be responsible for creating a pressure gradient and consequently intensification of the MOC. In CORE2 Experiment bias is controlled.