MICOM Sensitivity to Eddy-induced Mixing

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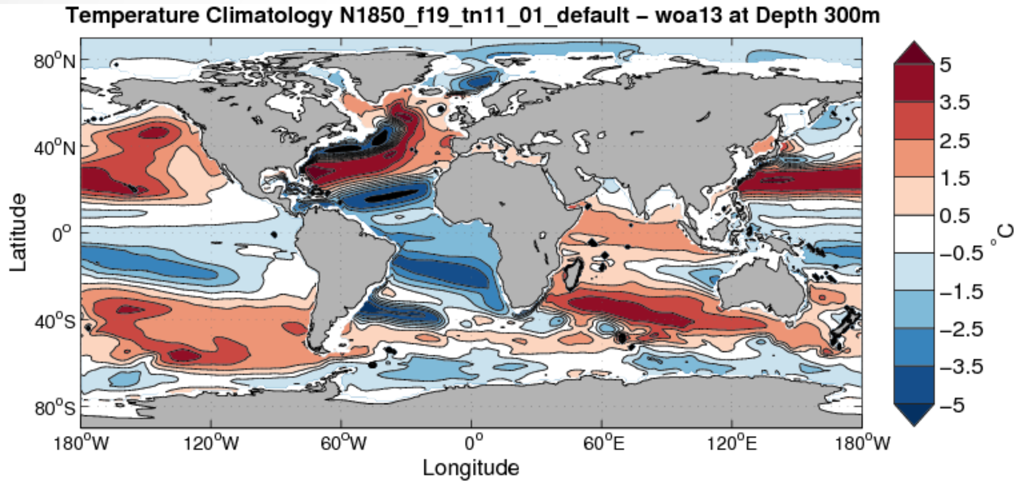
Outline

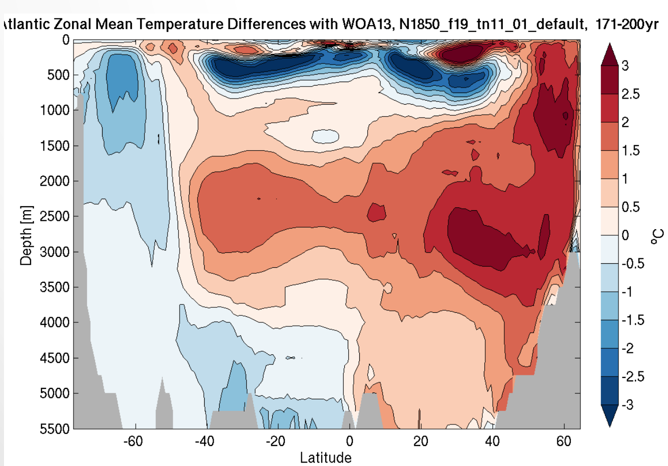
- Motivation: Understanding the biases in NorESM-1
- Sensitivity studies to explore the sensitivity of the ocean solution to the eddy-induced mixing parameterizations in MICOM
- North Atlantic Water Mass Transformation (WMTR) in NorESM

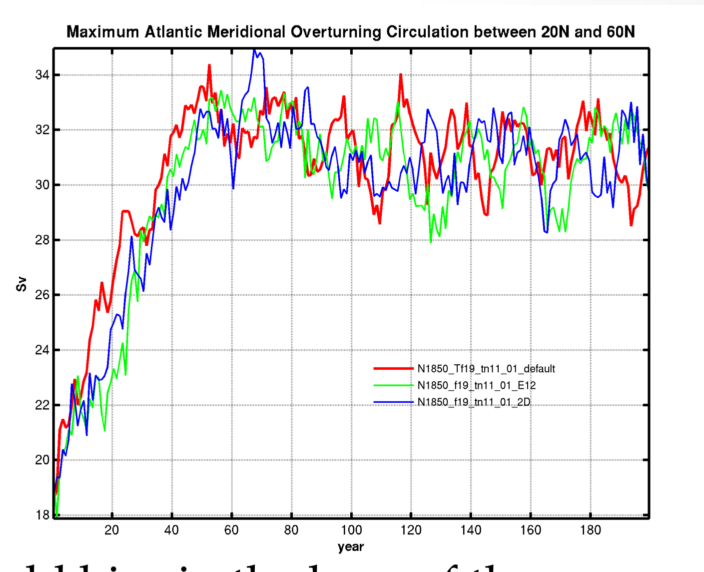
Understanding the biases in CMIP5 NorESM-1 (*Bentsen et al, 2013)*

N1850_f19_tn11_01_default**: 2° CAM4/CLM4, 1°tripole, 52 layers MICOM/CICE, pre-industrial configuration compared to **WOA13

Control







- Strong cold bias in the base of the thermocline;
- Warm bias in the intermediate waters;
- Cold bias in Southern Ocean;
- Intense AMOC ~30Sv (18Sv observed)

Eddy-induced mixing parameterizations in MICOM

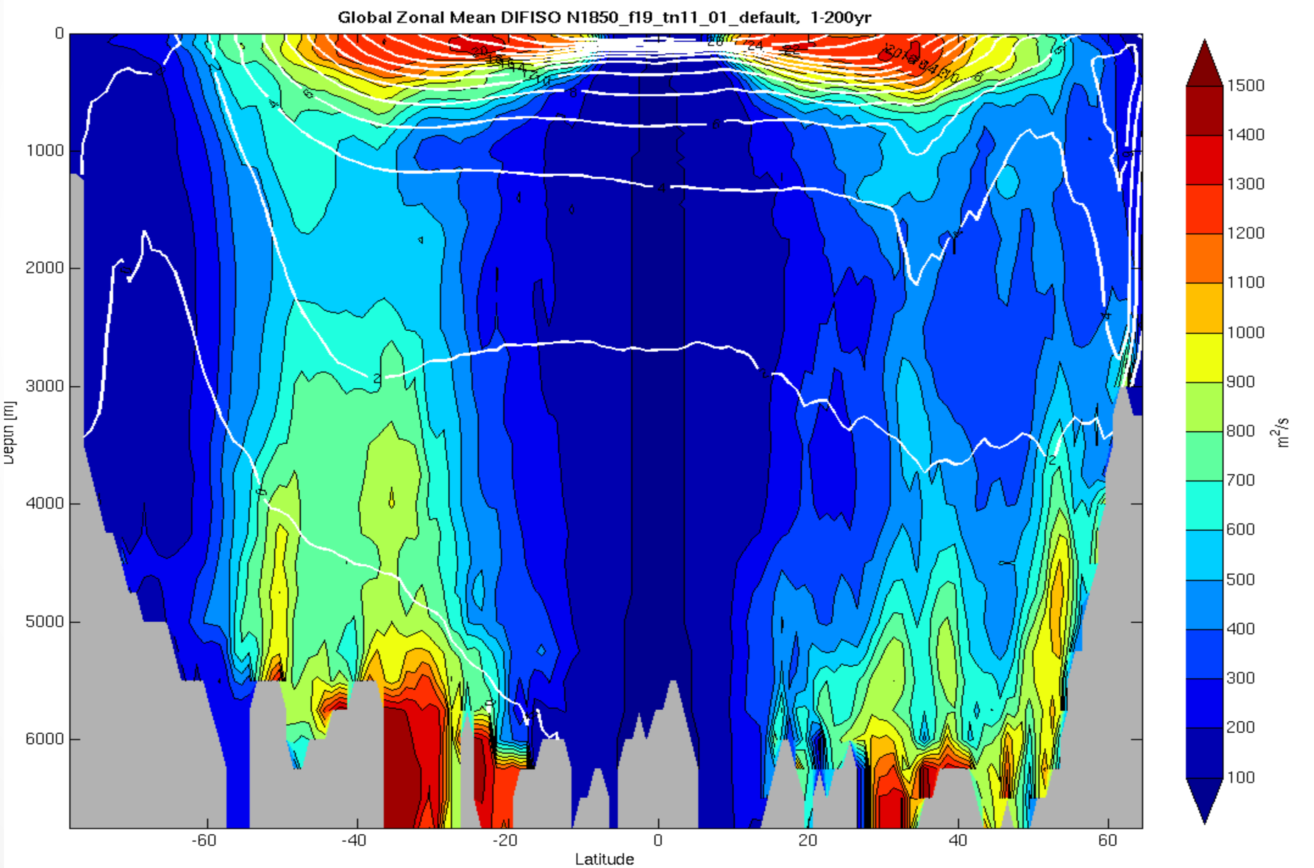
- 3-D diffusivity of isopycnal and thickness eddy diffusion parameterization based on Eden and Greatbach (2008), dependent on the eddy length and time scales.
- Thickness diffusion is parameterized by layer interface smoothing that resembles the Gent McWilliams (1990) parameterization in the subsurface ocean.
- Mixed Layer restratification by submesoscale eddies parameterized according to Fox-Kemper et al. (2008)

Sensitivity Experiments

ISOPYCNAL DIFFUSIVITIES SENSITIVITY EXPERIMENTS				
Exp/Param	EGC	EGMXDF	EGIDFQ	EGMNDF
Control (default)	1	1.50E+07	1	
EXP1 (E1)	0.5	1.50E+07	1	
EXP2 (E2)	0.75	1.50E+07	1	
EXP3 (E3)	1	1.00E+07	1	
EXP4 (E4)	1	7.50E+06	1	
EXP5 (E5)	1	1.50E+07	0.5	
EXP6	0.5	1.00E+07	1	
EXP12 (E12)	0.75	1.00E+07	0.5	
EXP14	1	2.00E+07	1	
EXP15 (E15)	Eddy induced mixing turned off			
EXP16 (E16)	1	1.50E+07	1	DIFISO
EXP17	1	1.50E+07	1	DIFINT
EXP_2D	2D parameterization implemented			
CORE2	as 2D but forced with CORE2			
SOUTHERN OCEAN SENSITIVITY EXPERIMENTS				
SO1	decreased (0.5) WS in SO (south of 45S)			
SO2	increased (1.5) Isopycnal Diff. in SO (south of 45S)			
MIXED LAYER PARAMETERIZATION SENSITIVITY EXPERIMENTS				
MLE	Mixed Layer Eddy Parameterization (Fox-Kemper) turned off			
MLE1	Reduced efficiency factor for wind TKE generation in MLP			
NEW MODEL DEVELOPMENTS				
MB01	as Control but with modified barotropic/baroclinic mass fluxes split			
MB03	as MB01 with new GM parameterization			

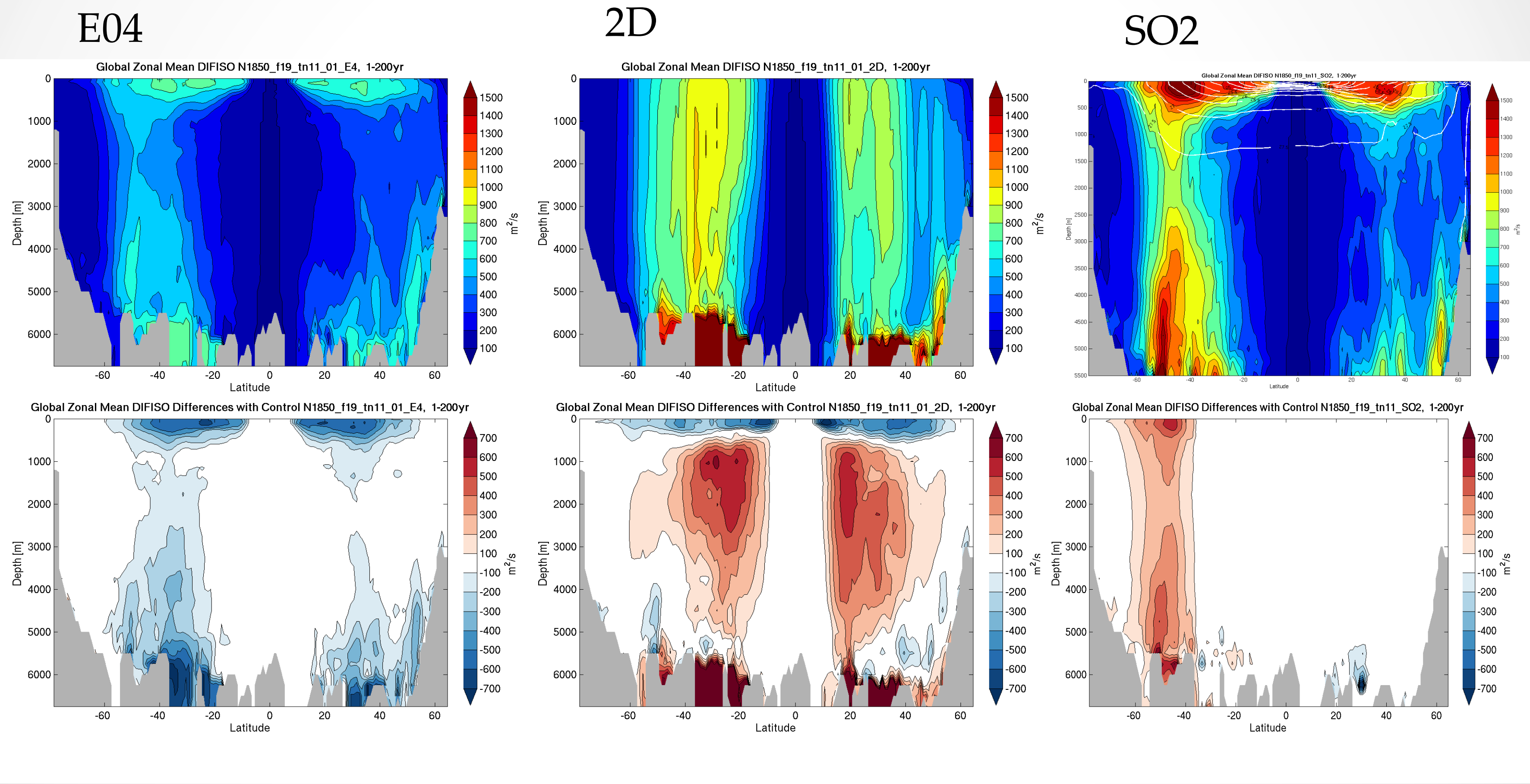
Global Zonal Mean Isopycnal Diffusivities in NorESM-Control

Control



Isopycnal Diffusivity Sensitivity Experiments

Atlantic Zonal Mean of the Isopycnal Diffusivities (top) and Differences with the Control run (bottom)

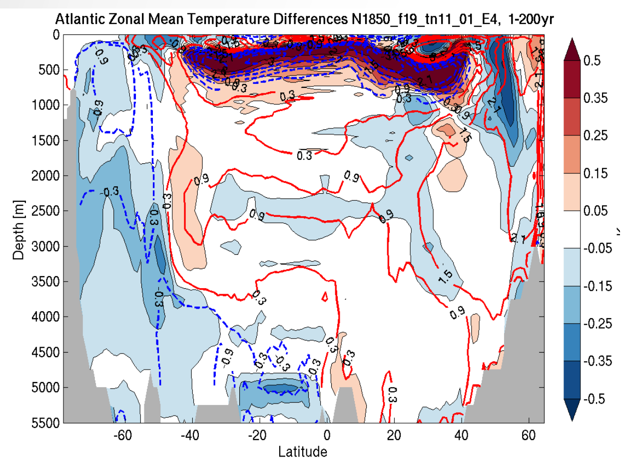


Exp.E04 – decreased twice the maximum diffusivity
Exp.2D - homogenized vertically the isopycnal mixing
Exp.SO2 - increased by 1.5 magnitude mixing south of 45S

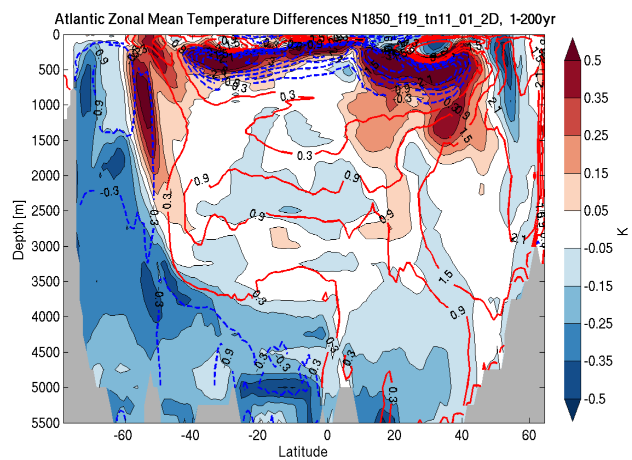
Isopycnal Diffusivity Sensitivity Experiments

Atlantic Zonal Mean Temperature Differences:
Sensitivity Exp – Control (Color) and Control – WOA09 (Contours)

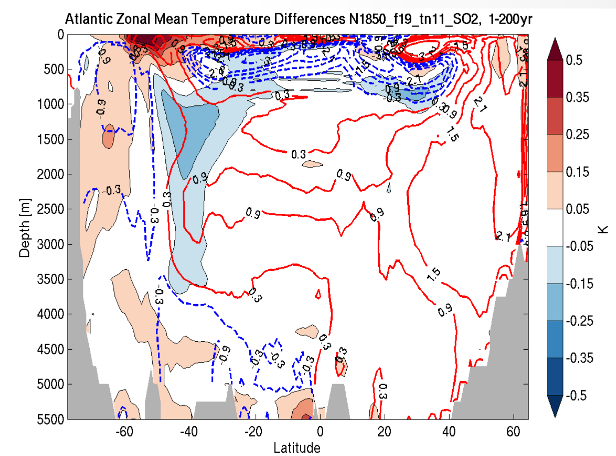
E04



2D



SO2



- The most improvement we achieved in Exp.E04
- Exp.2D improved biases in the entire water column.
- In all of the E-experiments though the SO cold and fresh bias was increased indicating that rather increased mixing is needed there.
- Exp.SO2 reduced the cold SO bias.

Water Mass Transformation Rate

Integrated measure of air-sea interaction and water mass formation

Water mass transformation function:
(*Speer and Tziperman 1986,1992, Bryan et al, 2006*)

$$Tr(\rho)\Delta\rho = \frac{1}{\tau}\int_{\tau}\iint_{outcrop} F_{\rho}\delta(\rho,\rho+\Delta\rho)\,dA\,dt$$

Where: $F_{\rho} = \frac{\alpha}{\rho_0 c_p}F_{heat} - \beta F_{water}\left(\frac{S}{1-S}\right)$ **- Sea surface density flux**

$\delta(\rho,\rho+\Delta\rho) = \begin{cases} 1-(\rho,\rho+\Delta\rho) \\ 0-elsewhere \end{cases}$

ρ_0 **-sea water density**

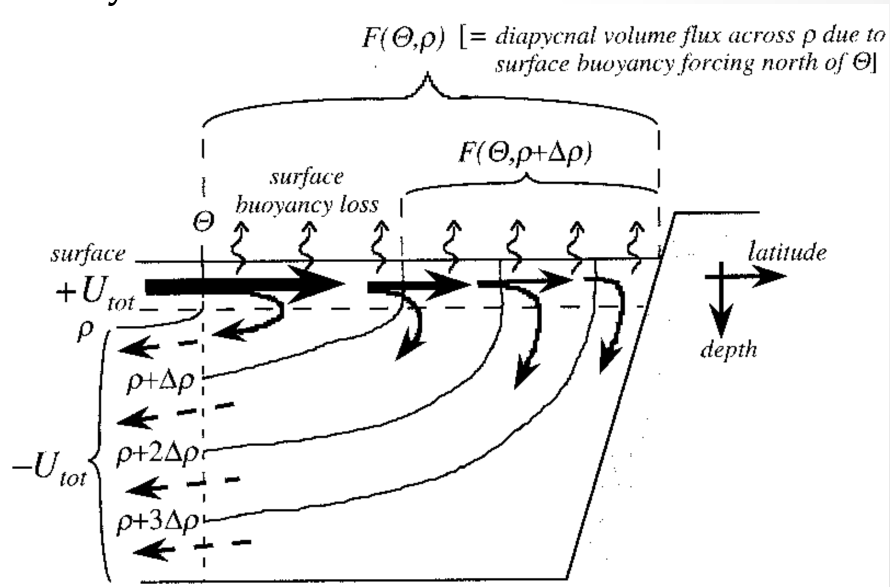
c_p **-specific heat,**

$\alpha = -\frac{\partial\rho}{\rho\partial T}$, $\beta = \frac{\partial\rho}{\rho\partial S}$ **- Thermal expansion and salinity contraction coefficients**

F_{heat}, F_{water} **- Surface heat flux and surface fresh water flux**

T, S, ρ **- Sea surface temperature, salinity and density**

$-\frac{\partial Tr}{\partial\rho}$ **- Water mass formation rate**

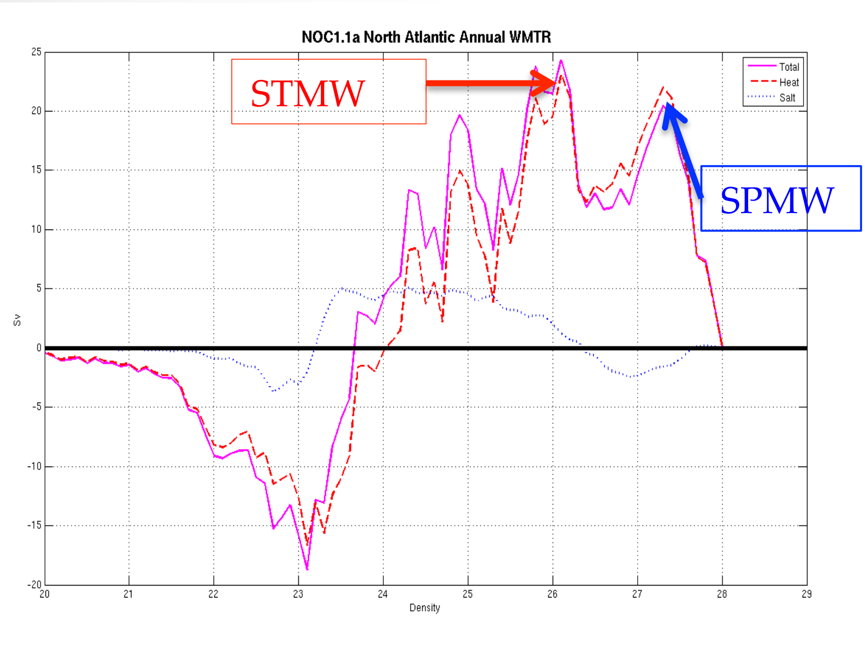


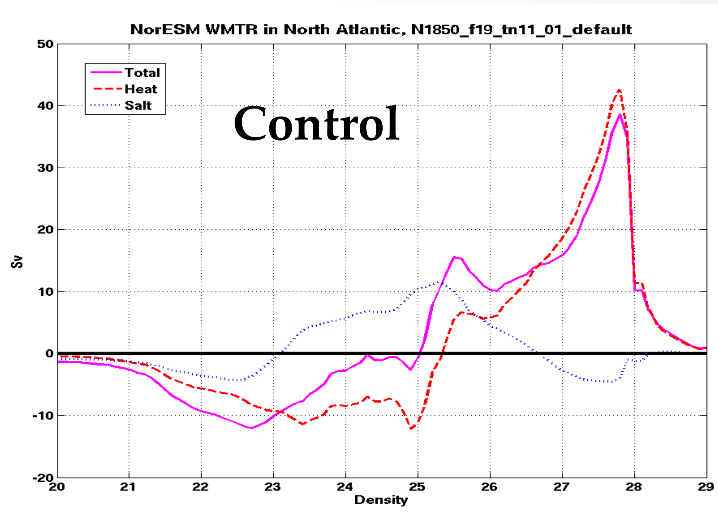
From Marsh, 2000

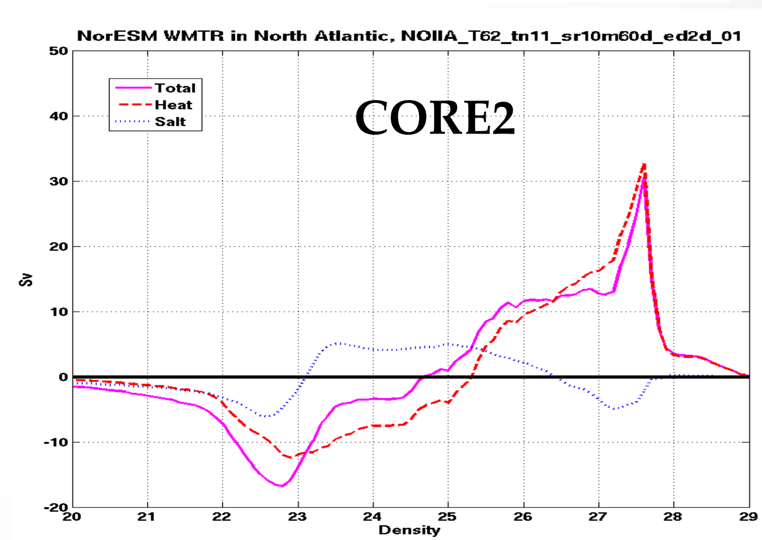
North Atlantic WMTR in NorESM-1

Observed Estimate:

UK National Oceanographic Center Flux Climatology 1.1a (NOC1.1a)



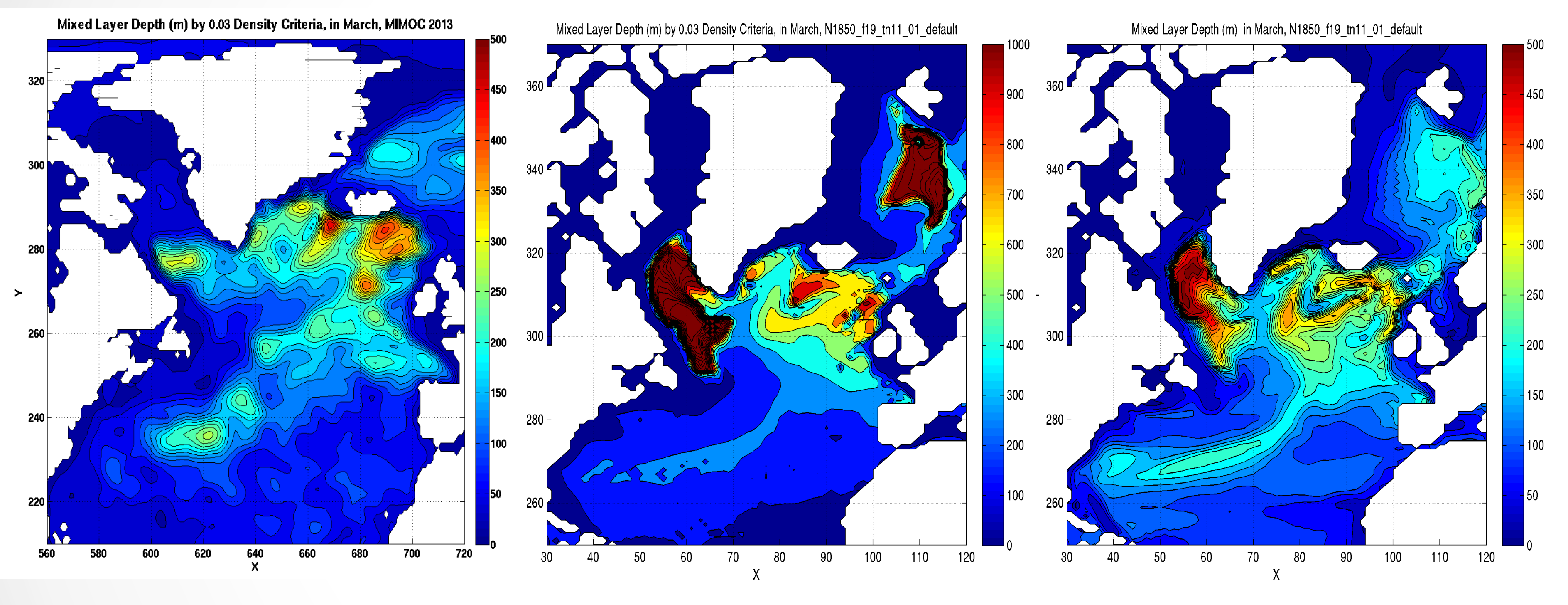




- **STMW Sub-Tropical Mode Water: sigma$_0$~26; 23Sv**
- **SPMW Sub-Polar Mode Water; sigma$_0$~27.43-27.5; 20Sv**

North Atlantic Mode Waters

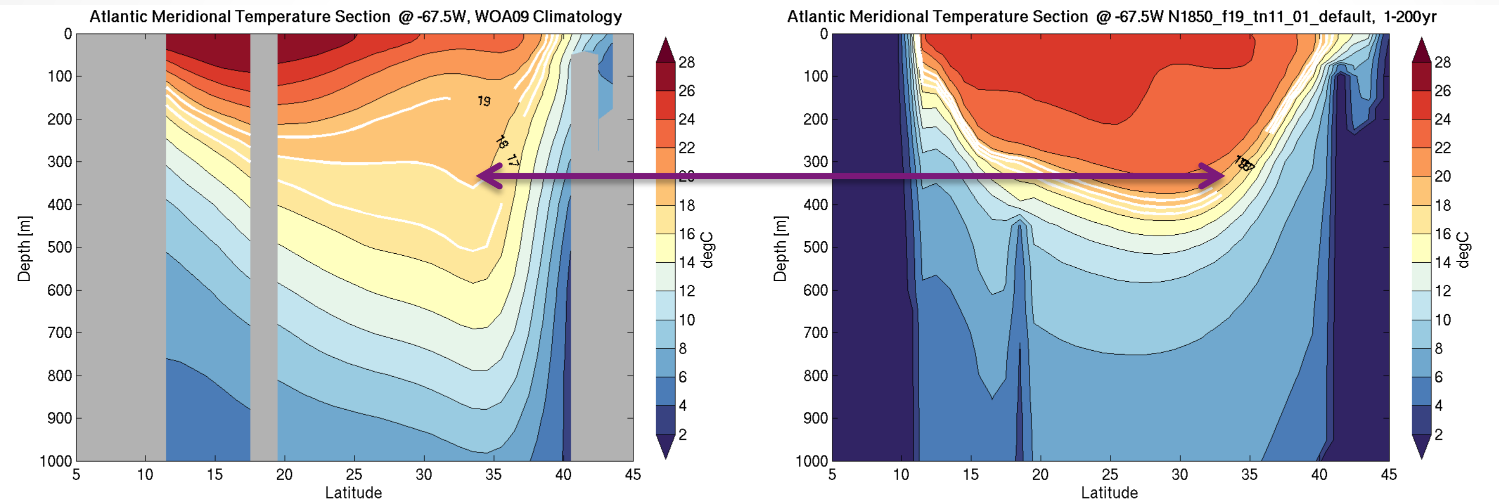
Mixed Layer Depth (m) comparison with MIMOC (2013), based on ARGO floats data, approach after Holte & Talley 2009

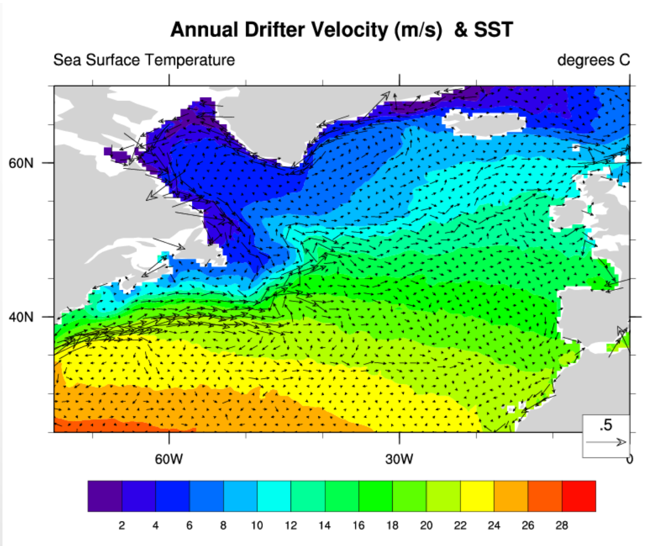


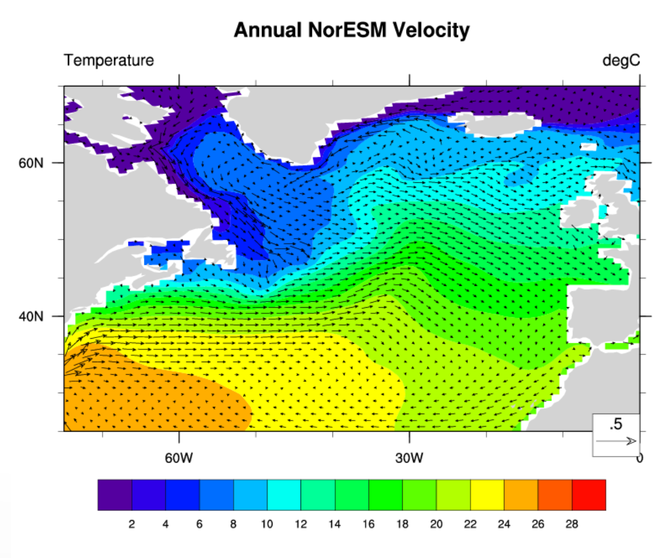
- Mode waters can be located in areas with deep mixed layers:
- STMW (18°water) forms south of Gulf Stream in the north-west corner of the sub-tropical gyre
- SPMW forms along the periphery of the sub-polar gyre

North Atlantic Mode Waters
STMW - 18deg Mode Water

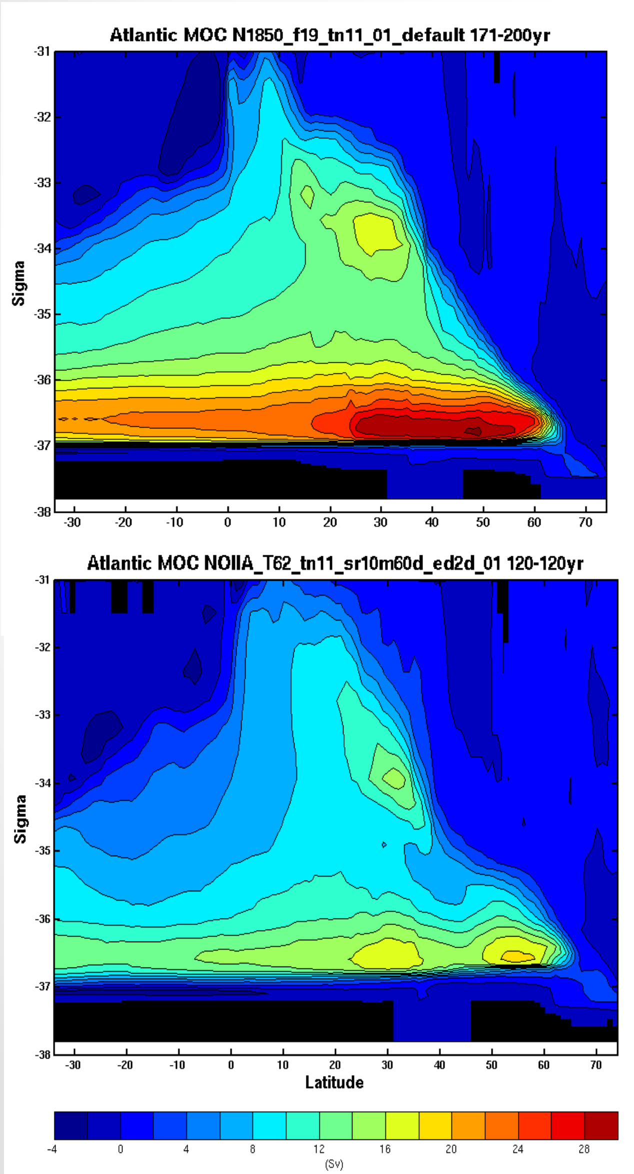
Temperature Meridional Section @ 65.5W in North Atlantic







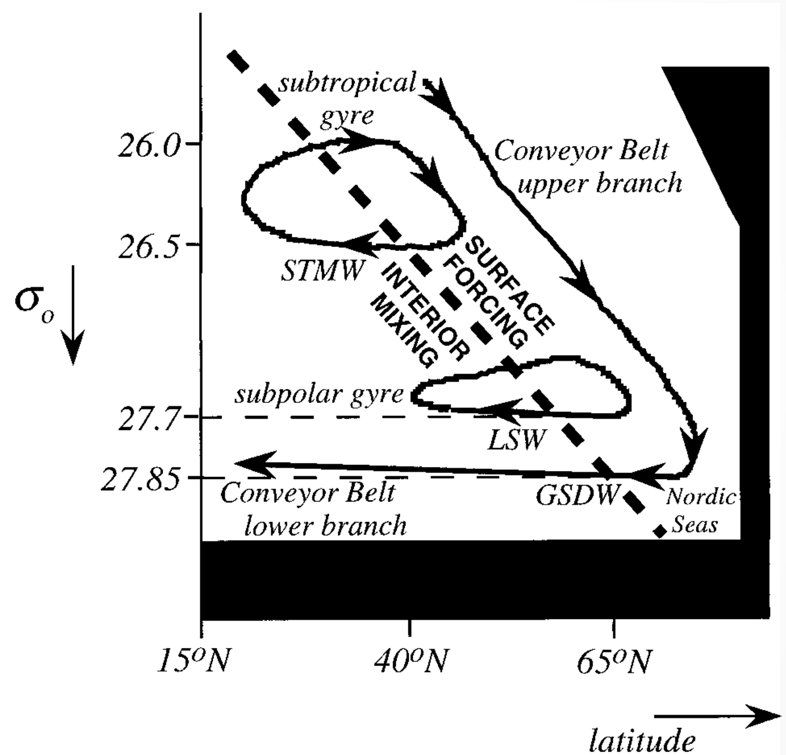
WMTR connection with AMOC



Control

CORE2

From Marsh, 2000



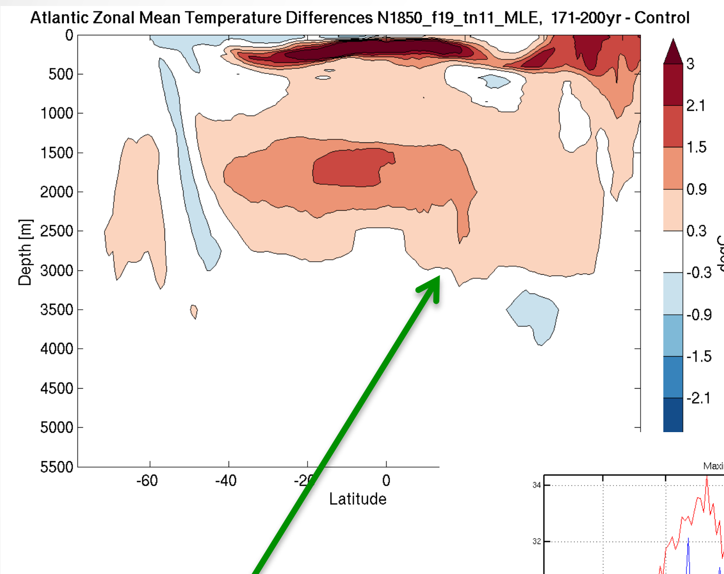
Relating the transformation of specific water masses to the overturning circulation

Sensitivity Experiments

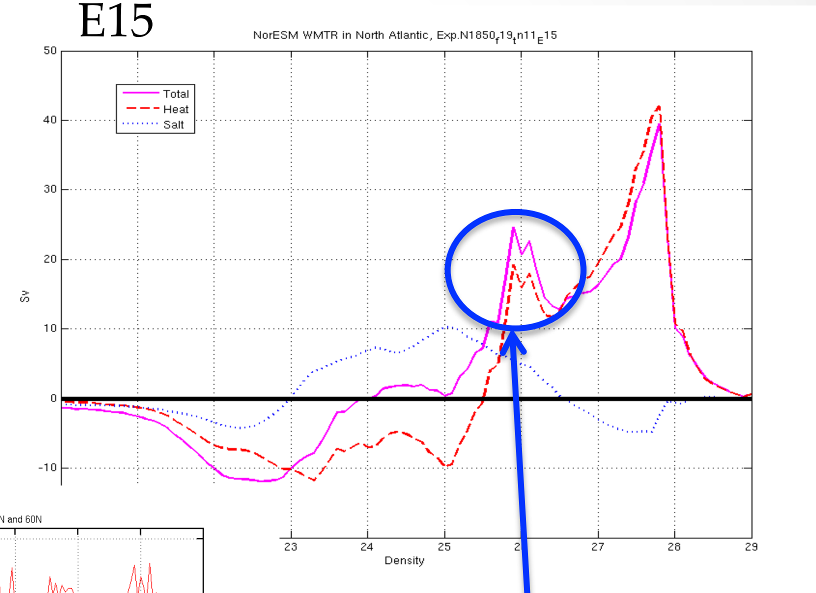
Experiment E15 – eddy induced mixing off

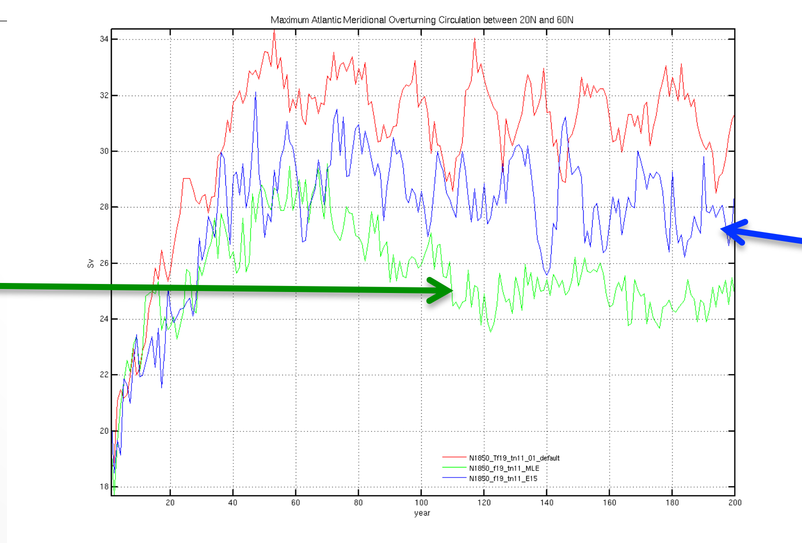
Experiment MLE – mixed layer submesoscale eddy param. off

MLE



E15





Exp **MLE**

Exp **E15**

Significant impact on:

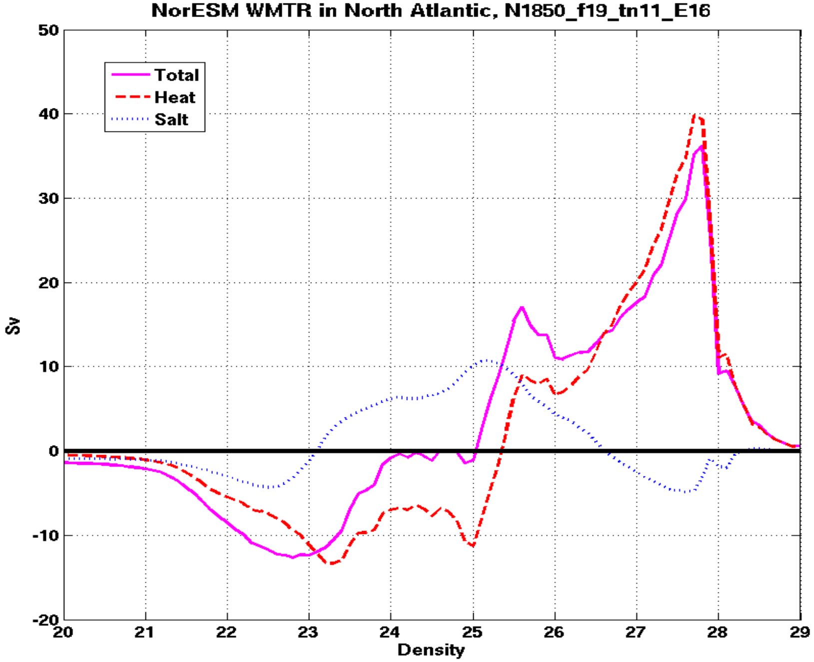
- AMOC ~5-6Sv
- Upper 3000m ocean

- STMW appears
- AMOC impact~2Sv

Sensitivity Experiments

Experiments E16 & E17 - Testing the GM mixing

E16

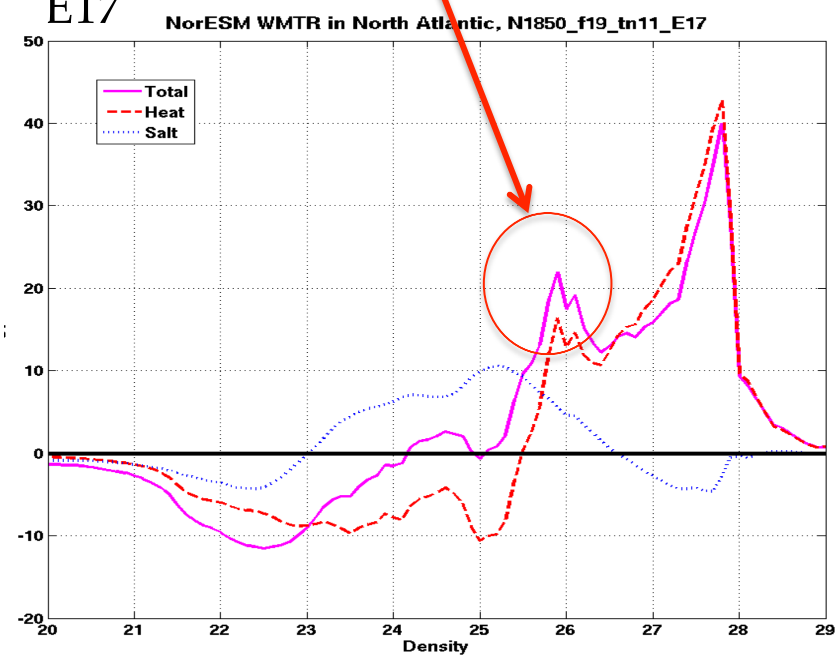


Exp **E16** – layer interface mixing only, based on GM parameterization.

Exp **E17** - isopycnal mixing only.

- STMW at the observed transformation rate (~20Sv)
- STMW in the correct density class sigma$_0$~26

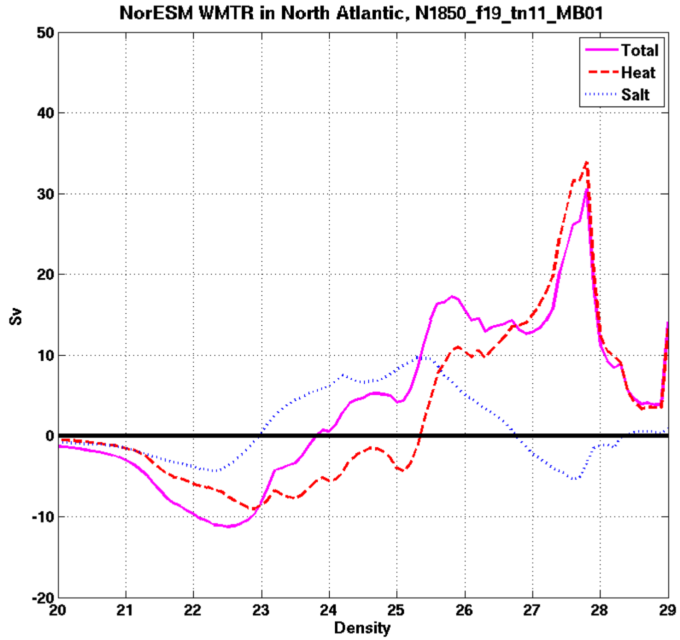
E17



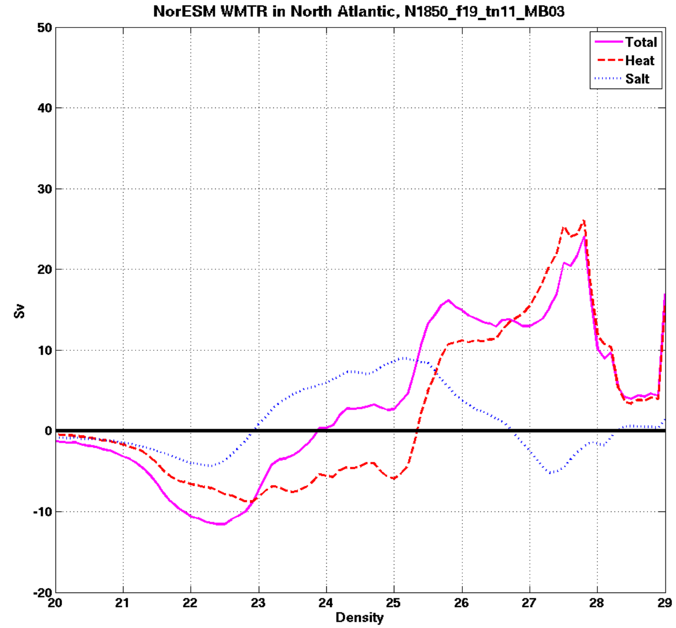
New Model Developments

Experiments MB01 & MB03

MB01



MB03



- N1850_f19_tn11_MB01: Same as N1850_f19_tn11_01_default but with modified procedure of making barotropic/baroclinic mass fluxes consistent. Also modified application of eddy-induced mass fluxed in the advection routine.
- N1850_f19_tn11_MB03: Same as N1850_f19_tn11_MB01, but with new GM parameterization.

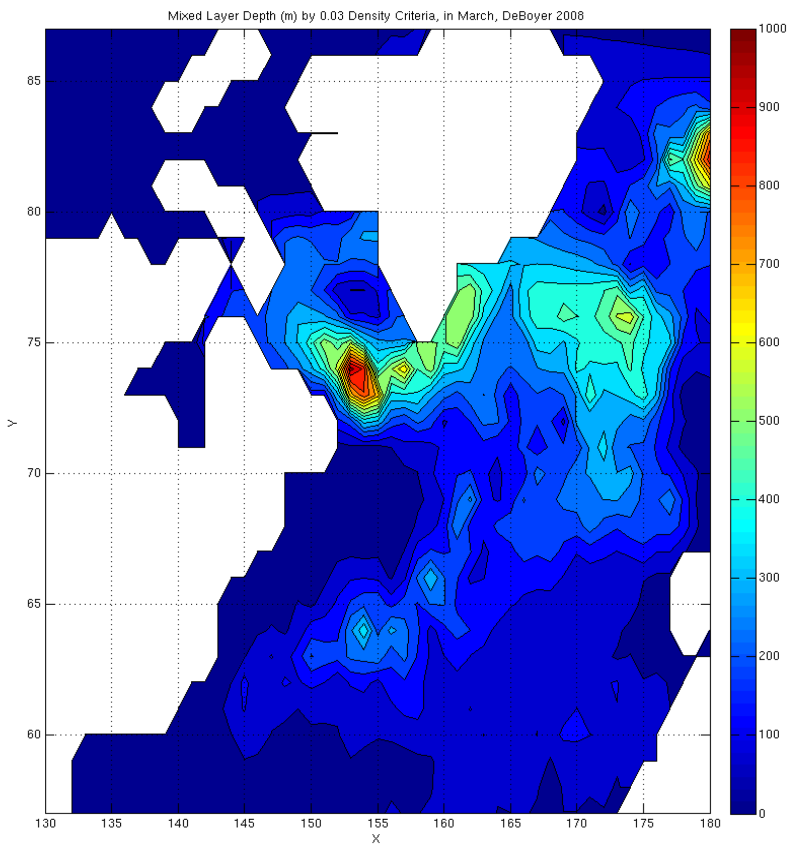
Conclusions

- The eddy-induced mixing sensitivity experiments showed that its decreasing and vertical homogenizing improves the overall biases in the thermohaline structure indicating that lower values of parameters should be used in the parameterization; Exception is the Southern Ocean where in contrast the eddy-induced mixing should be increased;
- We demonstrated that the WMTR is a useful metrics to evaluate the fidelity of both air-sea fluxes and water mass formation. The WMTR are directly related to the meridional overturning circulation and their improved simulation will improve the MOC as well;
- In the CMIP5 NorESM-1 (Control) there is a tendency of excessive production of SPMW and the STMW is formed in a rather lighter density classes and smaller rates. The salinity restoring in the forced simulation (CORE2) seems to fix the mismatch in the STMW density, but still the simulation has a tendency to overestimate SPMW formation;
- The current implementation of the GM (interface mixing) seems to be responsible for the bias in the STMW formation which motivated development of new implementation of GM (MB03); The preliminary results from the latest model developments (improved baroclinic/barotropic split (MB01) and GM (MB03) representation show overall improved SPMW (reducing its WMTR to realistic rates);
- The mixed layer parameterization tests showed significant impact on the AMOC intensity (5-6Sv increased) and upper ocean thermohaline structure (suppressed warm bias); Further tuning with the latest developments is undergoing.

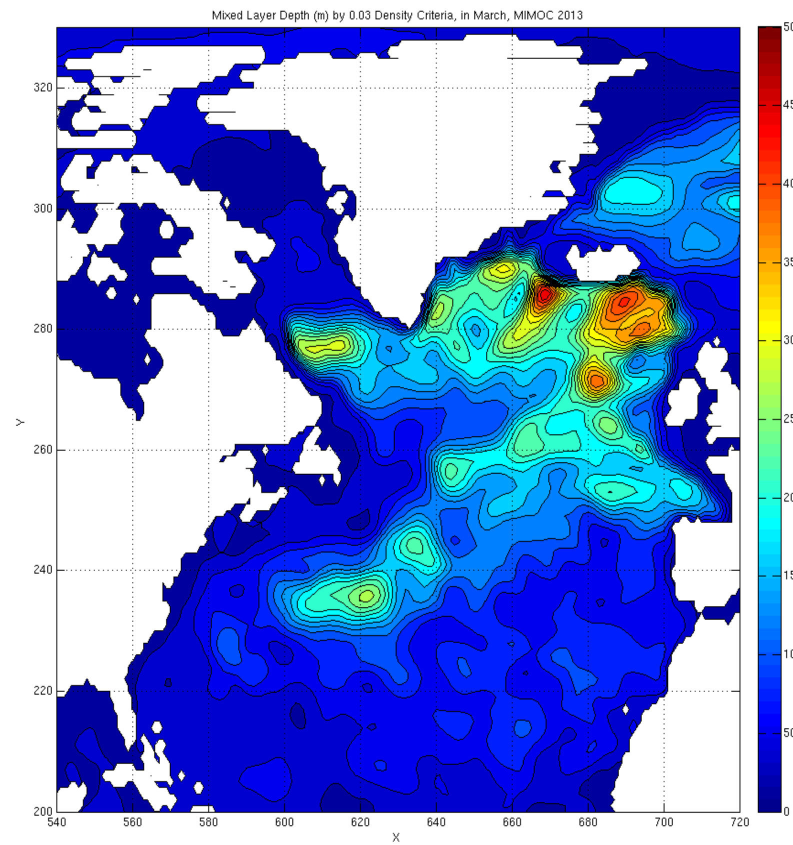
Thank you!

MLD003 Observations

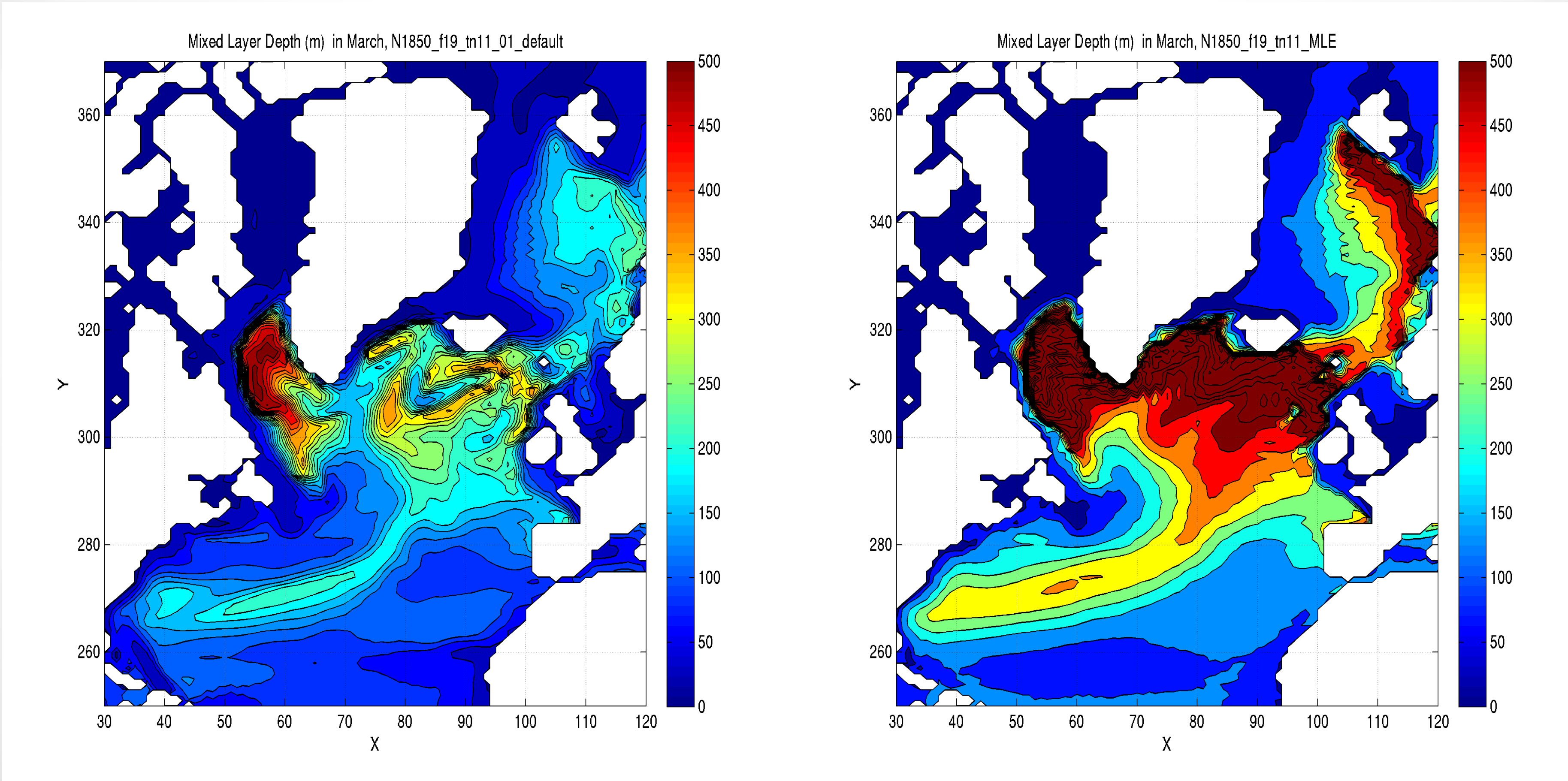
De Boyer, 2008, 2deg



MIMOC, 2013, 0.5deg,
approach after Holte&Talley 2009



NorESM MLD



MICOM MLD calculation shows much deeper MLDs then when MLE is not used. MLE is swallowing the mixed layer.