Dynamical Effects of a Stochastic Parameterization to Account for Uncertainties in the Horizontal Density Gradient of a Coarse-Resolution Ocean Model (MOM6)

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Introduction

SGS T & S Variability with Nonlinear Seawater EOS

- $T = \overline{T} + \Delta T, \quad S = \overline{S} + \Delta S$
- Coarse-resolution ocean model:

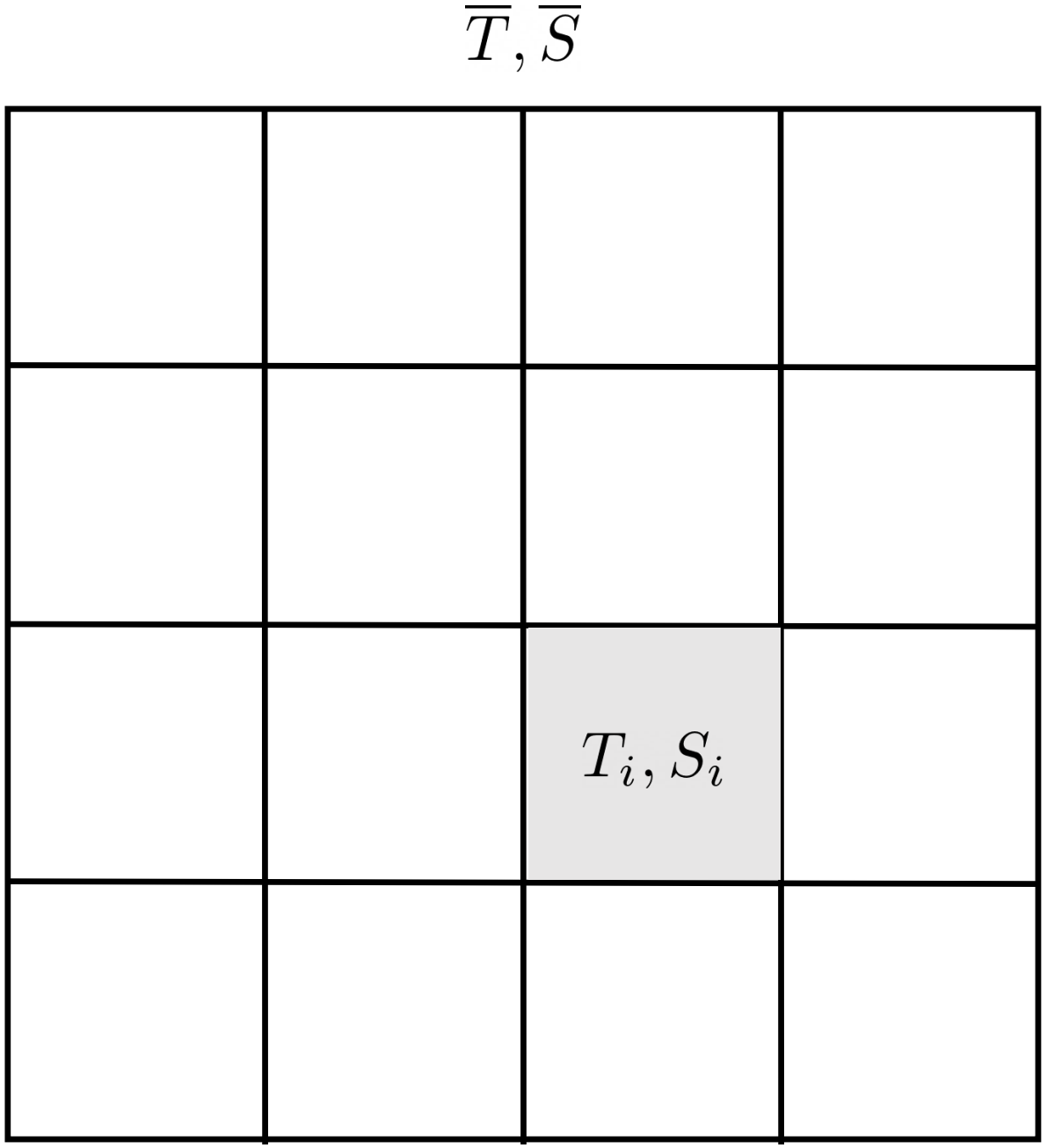
$$\rho_m = \hat{\rho}(\overline{T}, \overline{S})$$

- Grid-cell mean density:

$$\overline{\rho} = \frac{1}{V} \int_G \hat{\rho}(\overline{T} + \Delta T, \overline{S} + \Delta S) \; dx$$

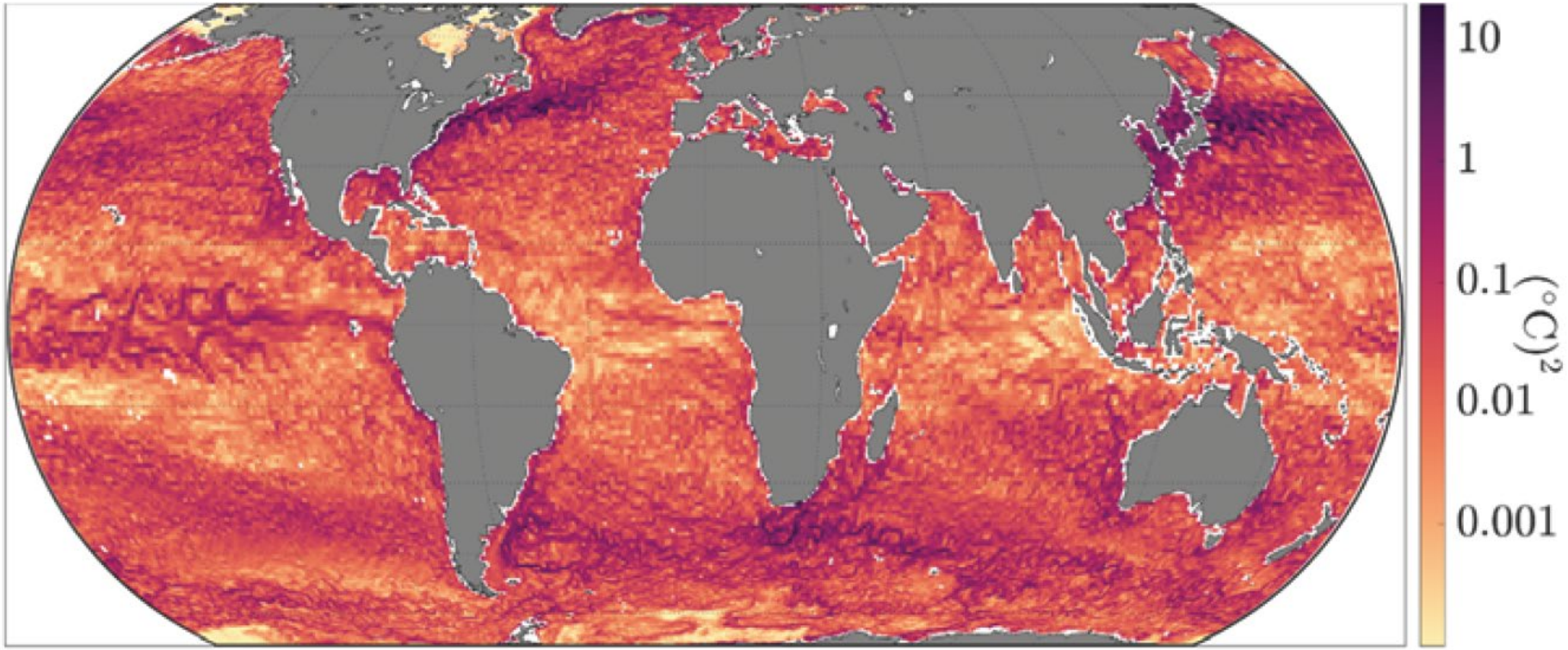
$$\overline{\rho} \approx \rho_m + \frac{\partial_T^2 \hat{\rho}(\overline{T}, \overline{S})}{2} \sigma_T^2$$

- See *Stanley et al. (2020)*



Unresolved SGS Temperature Variability

T Variance on ~1° Grid Diagnosed from ~0.1° POP Model



$$\sigma_T^2 \approx \sum_{i=1}^{N} w_i (\Delta T_i)^2$$

Figure adapted from *Stanley et al. (2020)*

Potential Density Correction

ρ Correction on ~1° Grid Diagnosed from ~0.1° POP Model

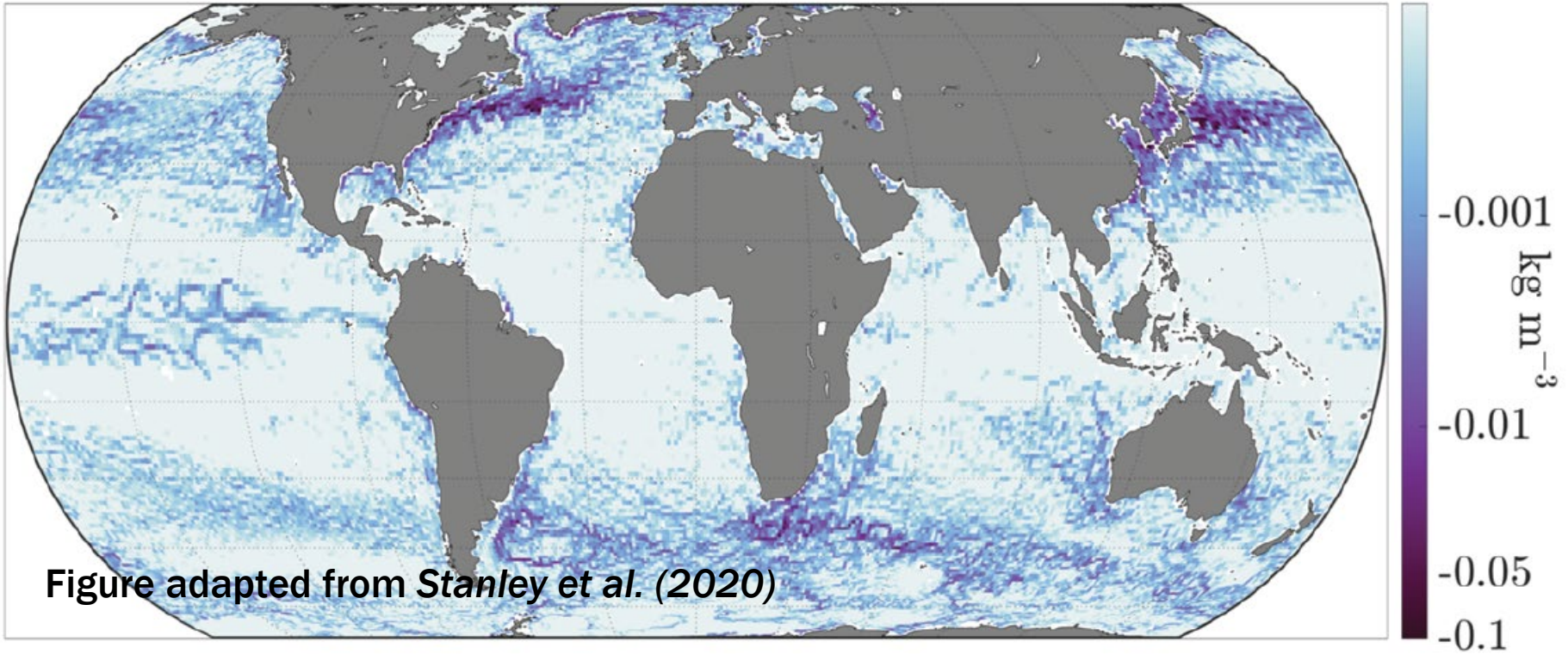


Figure adapted from *Stanley et al. (2020)*

$$\rho_c = \overline{\rho} - \rho_m$$

$$\overline{\rho} \approx \sum_{i=1}^{N} w_i \hat{\rho}(T_i, S_i)$$

***Brankart (2013)*: A stochastic parameterization improves WBC separation, SSH field**

Stanley (2020) Parameterizations of SGS T Variance

- Deterministic parameterization:

$$\sigma_T^2 \approx c \left| \delta x \circ \nabla \overline{T} \right|^2$$

- Stochastic parameterization:

$$\sigma_T^2 \approx c e^{\chi} \left| \delta x \circ \nabla \overline{T} \right|^2$$

- χ given by an AR-1 process

Model Validation

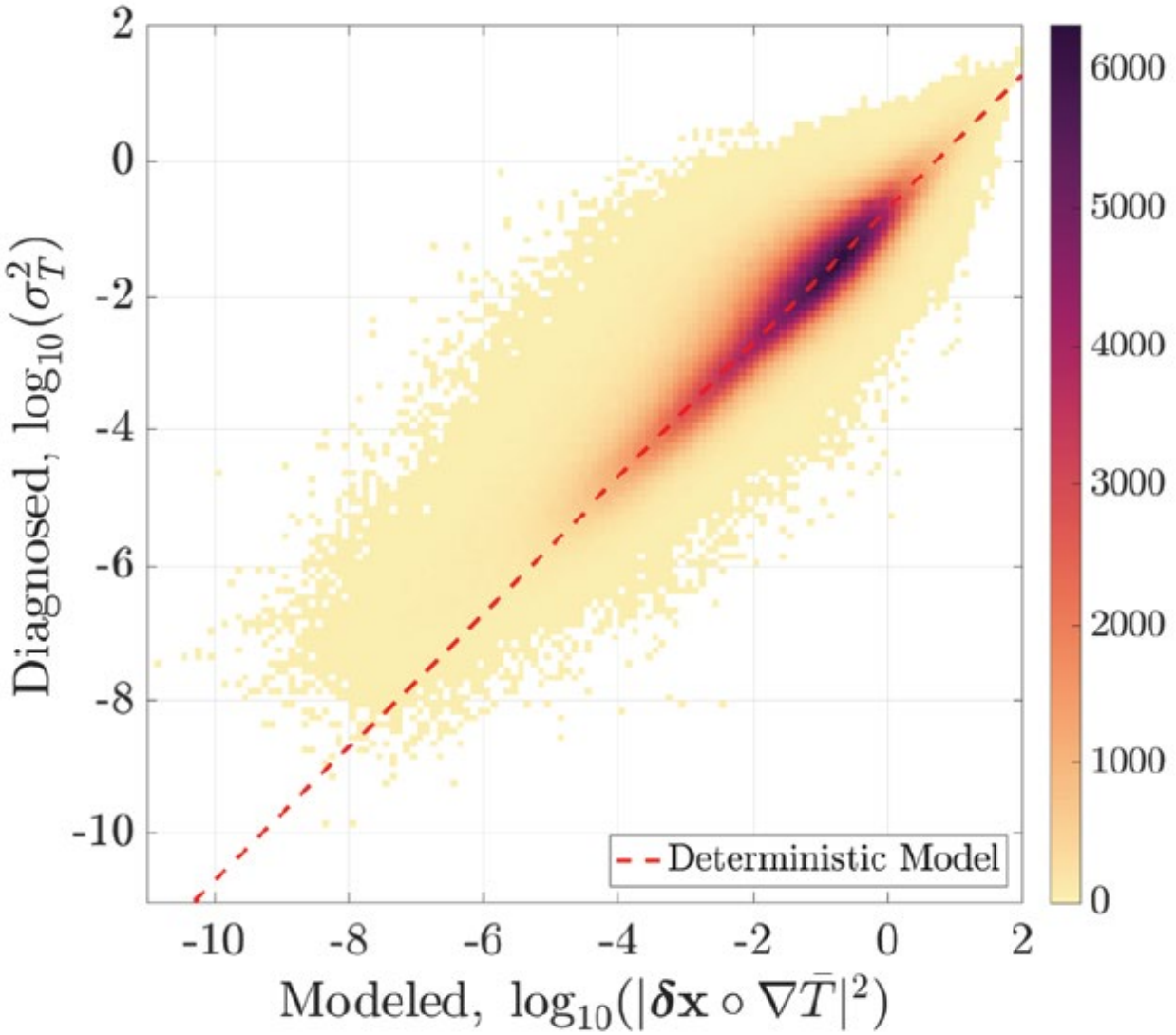


Figure adapted from *Stanley et al. (2020)*

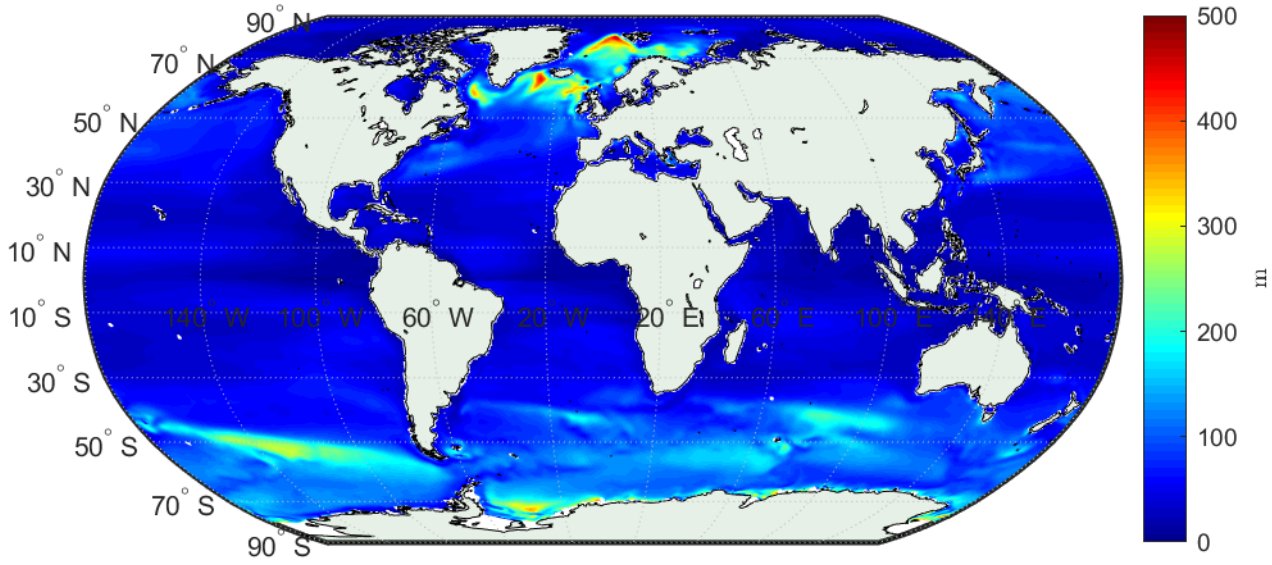
Experimental Configuration

- MOM6 + CICE 5
- 1-cycle JRA-55 forcing (1958-2015)
- Global domain
- ~0.66° horizontal resolution
- 65 z* vertical layers
- Branch from existing “best” simulation

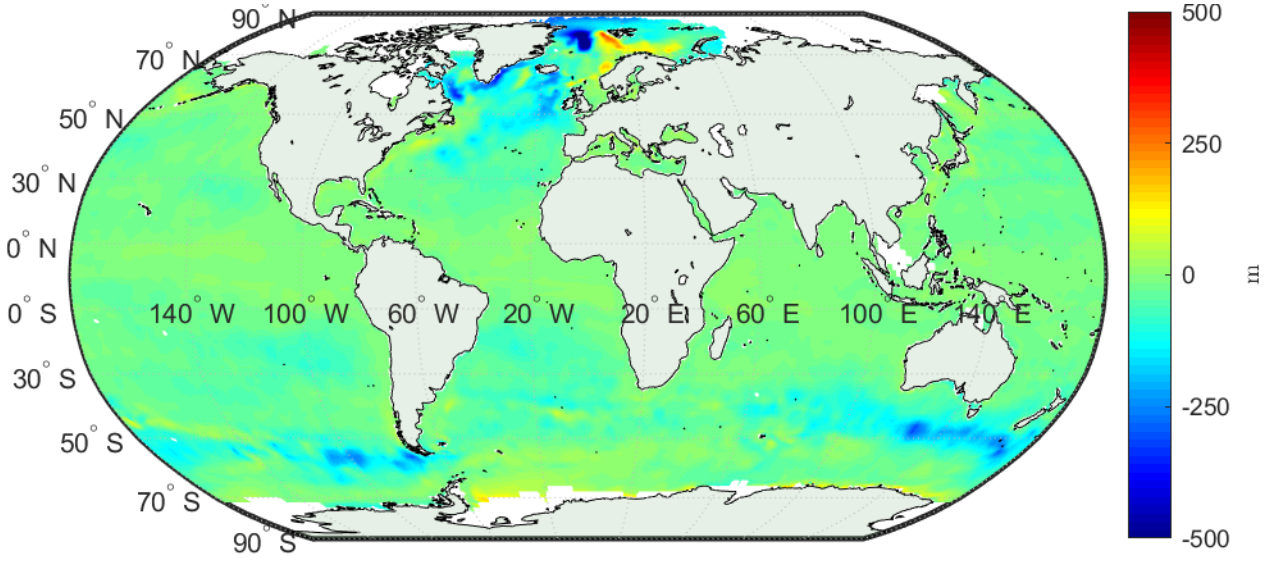
#	Experiment	Description
1	**Control**	**None**
2	Det	Deterministic PGF & GM
3	Det PGF	Deterministic PGF Only
4	Det GM	Deterministic GM Only
5	Stoch	Stochastic PGF & GM
6	**Stoch PGF**	**Stochastic PGF Only**
7	Stoch GM	Stochastic GM Only

Winter (JFM/JAS) Mixed Layer Depth

Control

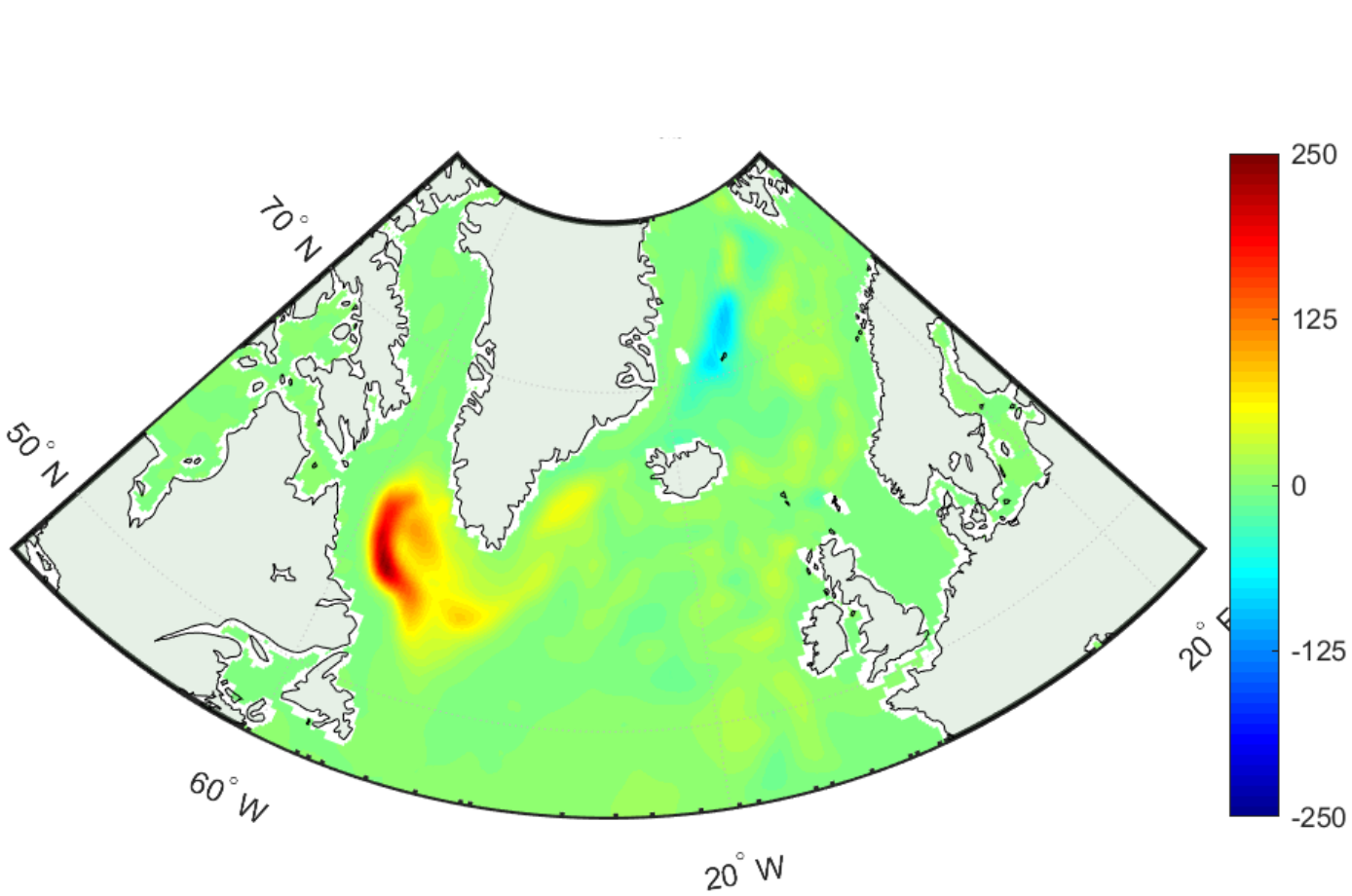


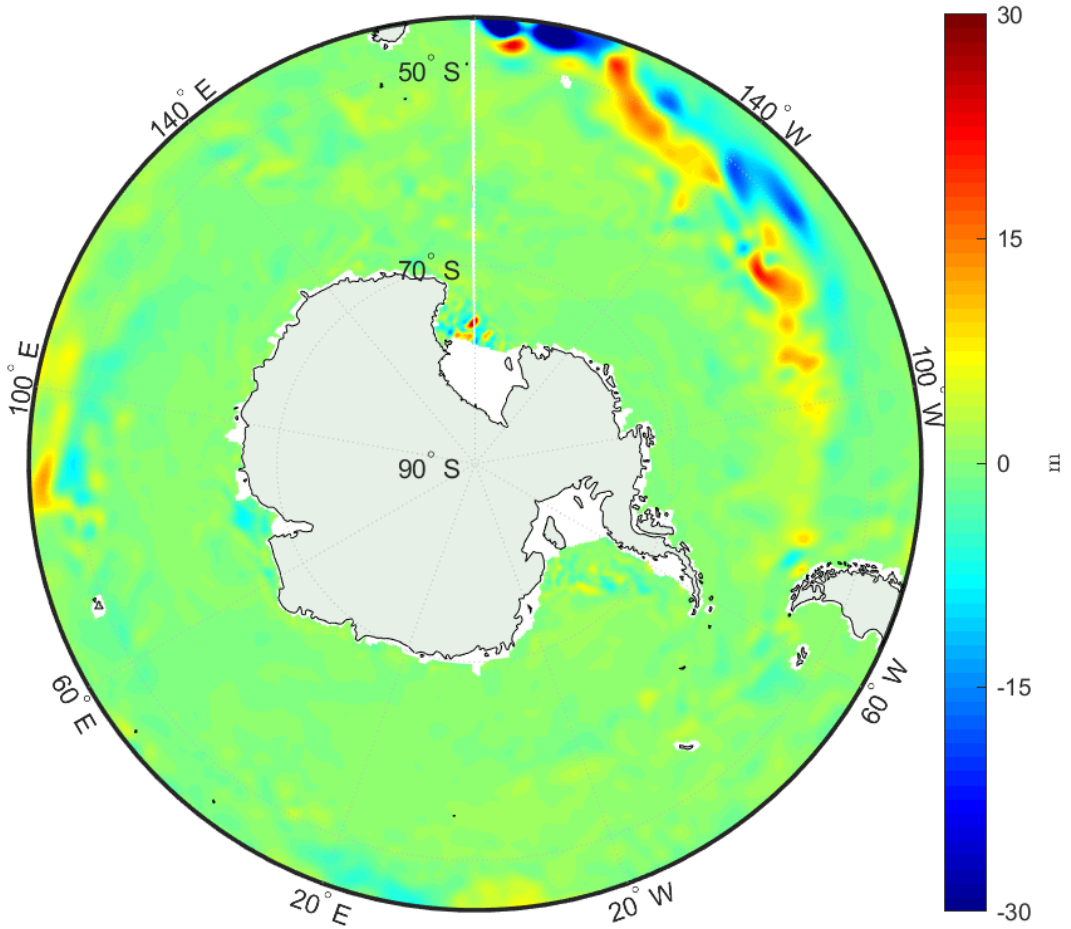
Control – deBoyer (2004) Clim



Winter (JFM/JAS) MLD Change

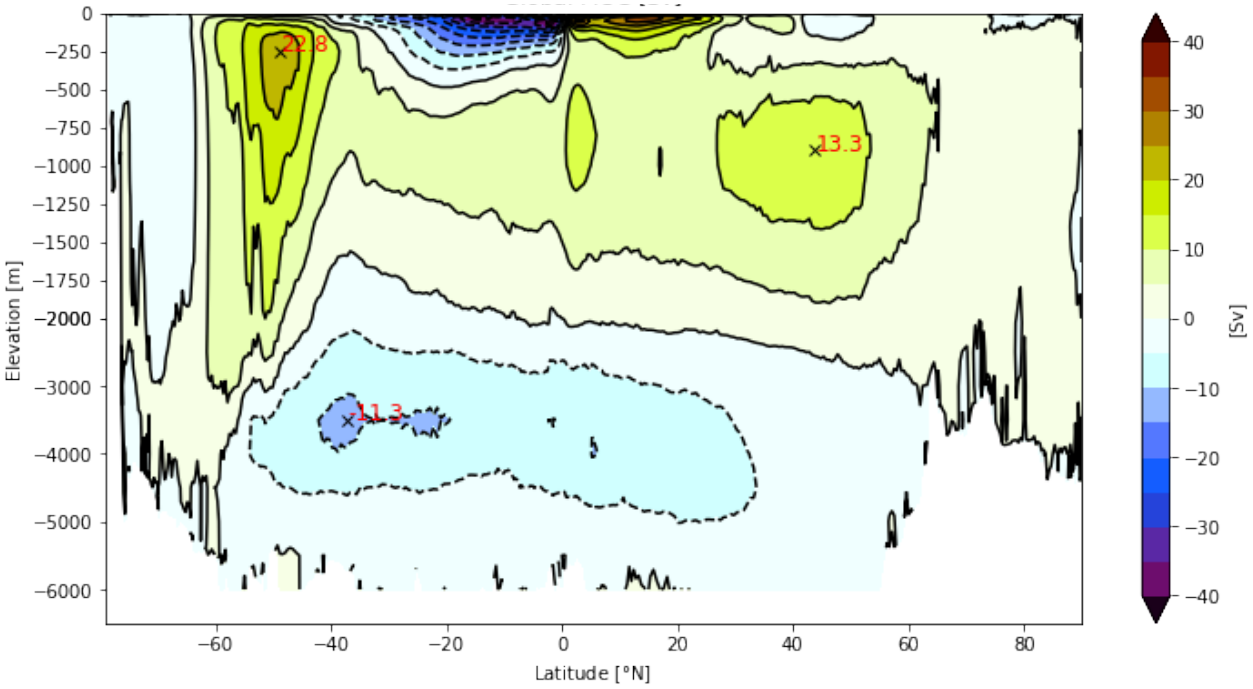
Expt - Control





Global Overturning Streamfunction

Control



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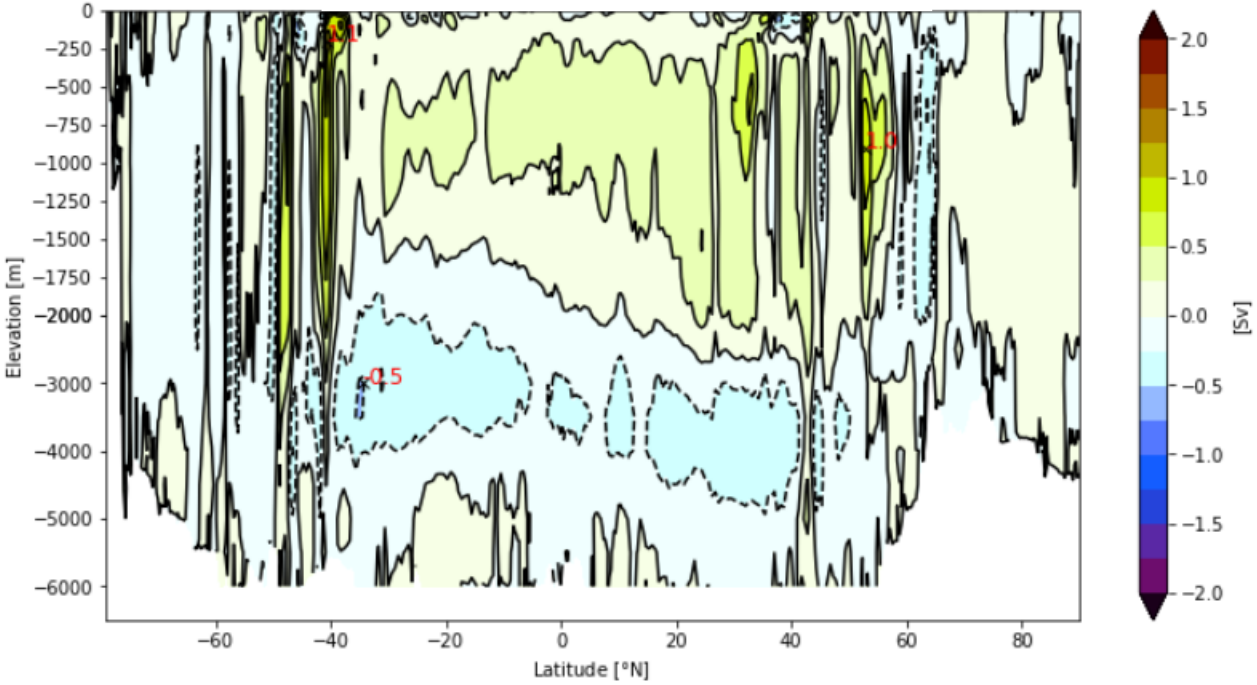
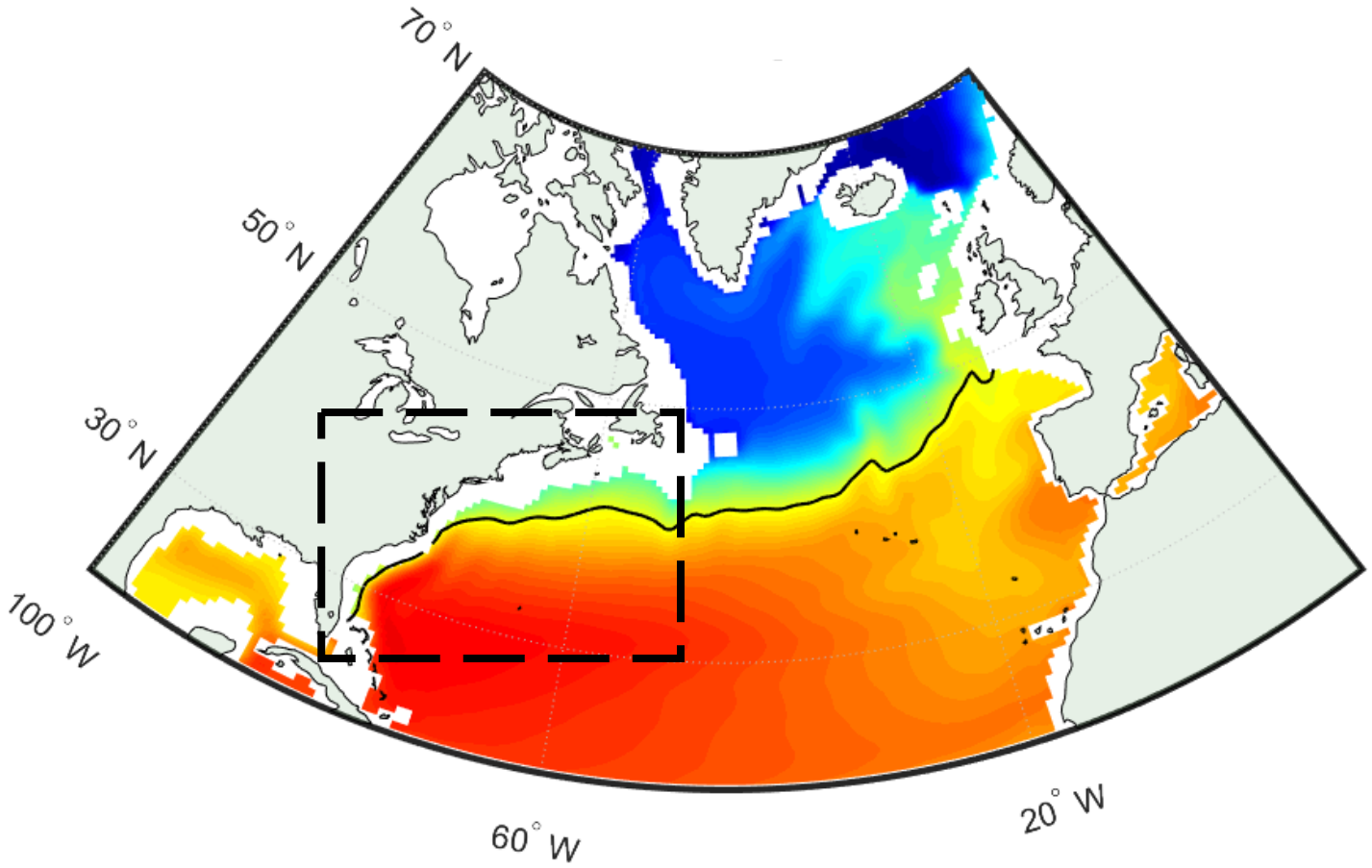


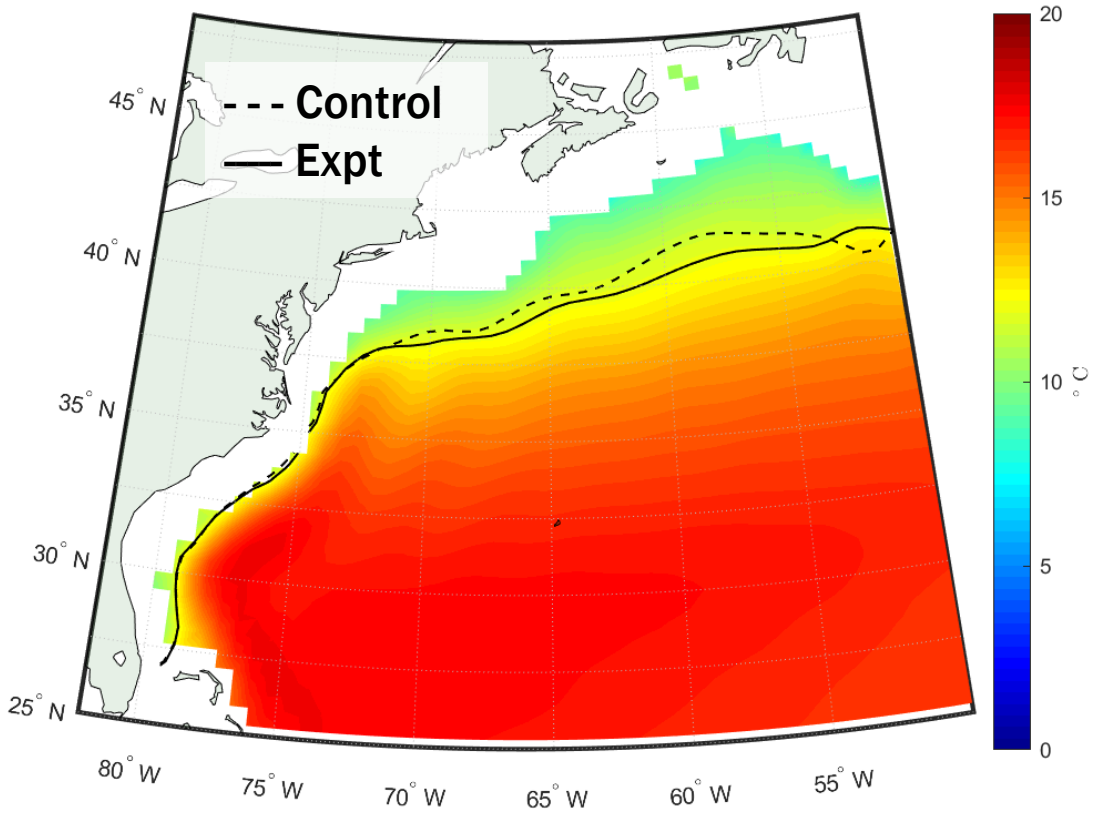
Thanks to Gustavo Marques for visualization tools

Gulf Stream Path – Potential Temperature (400 m)

Control

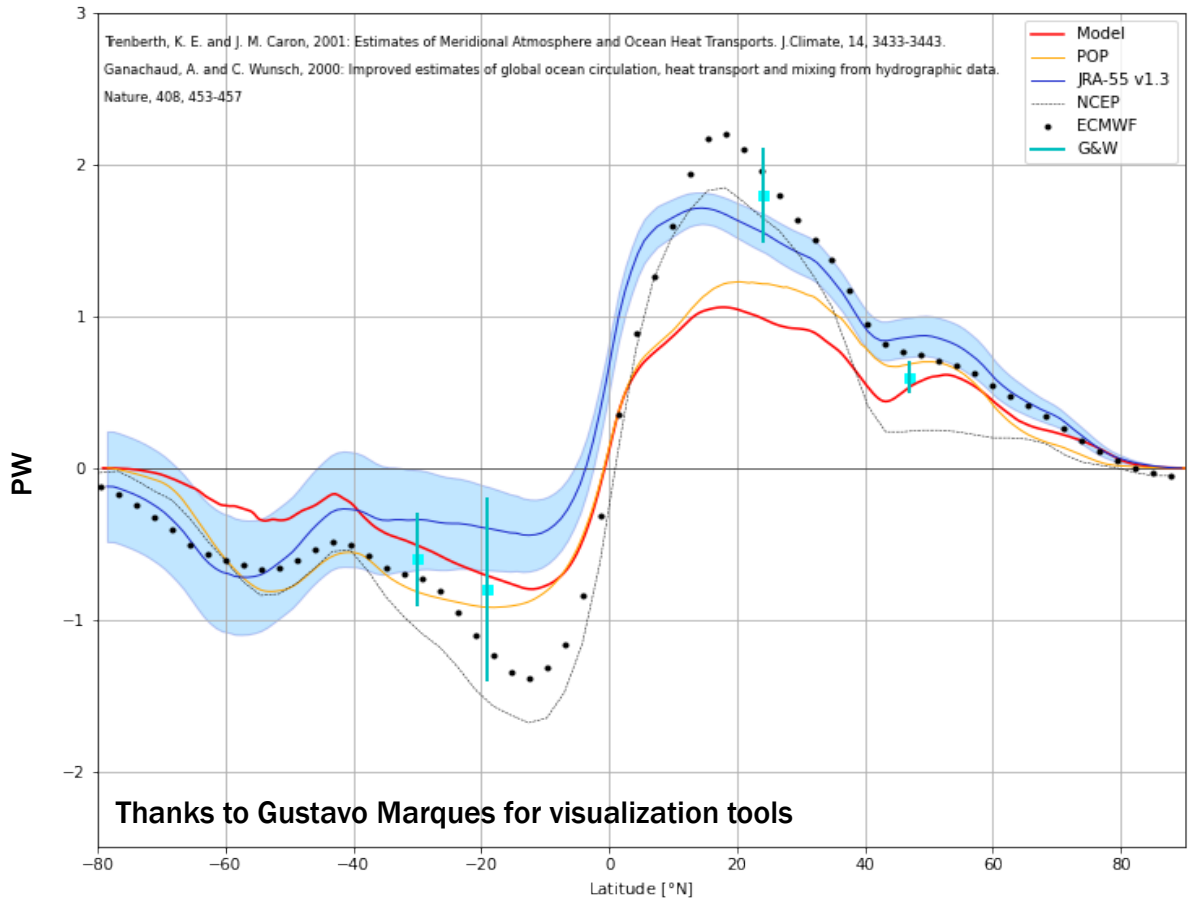


Expt



Meridional Heat Transport

Control



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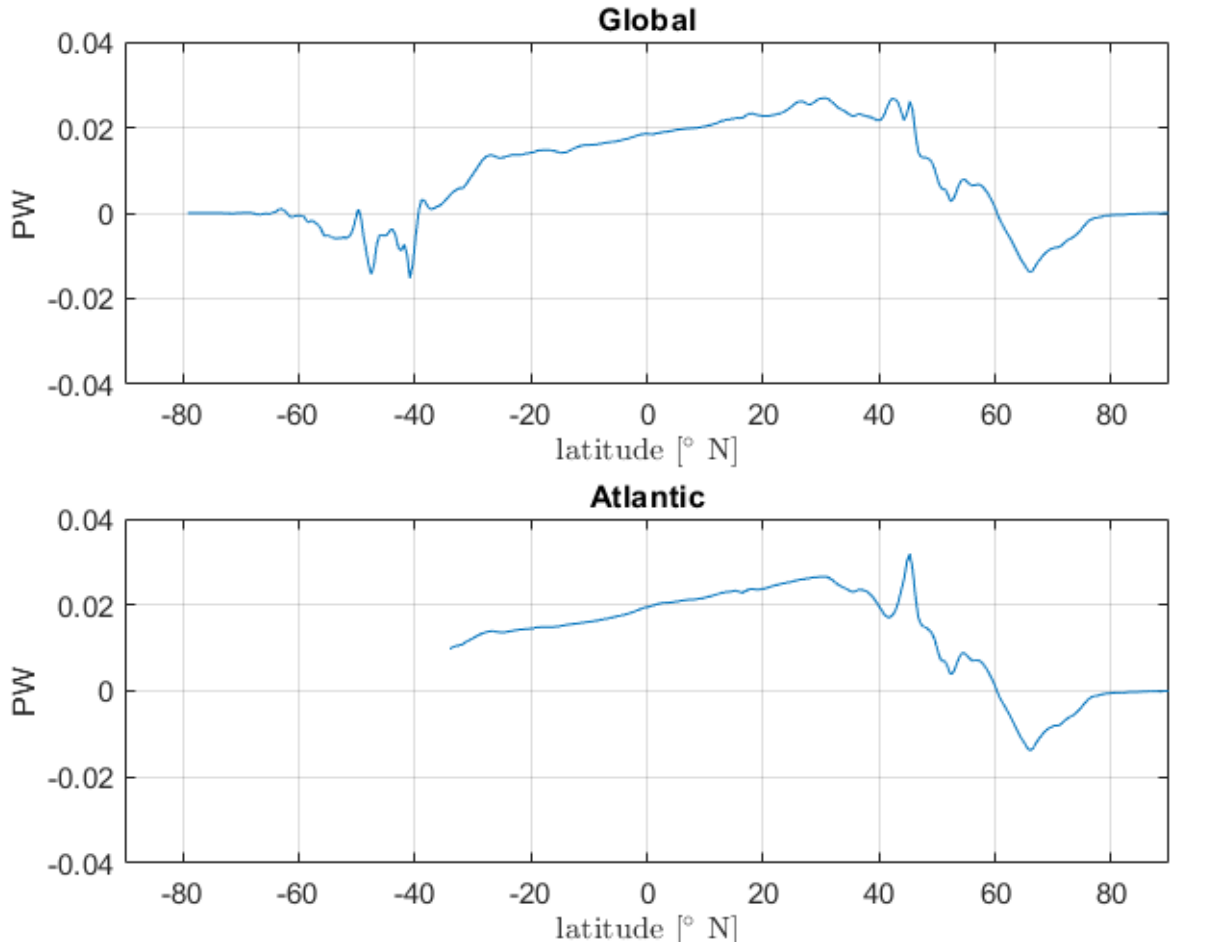
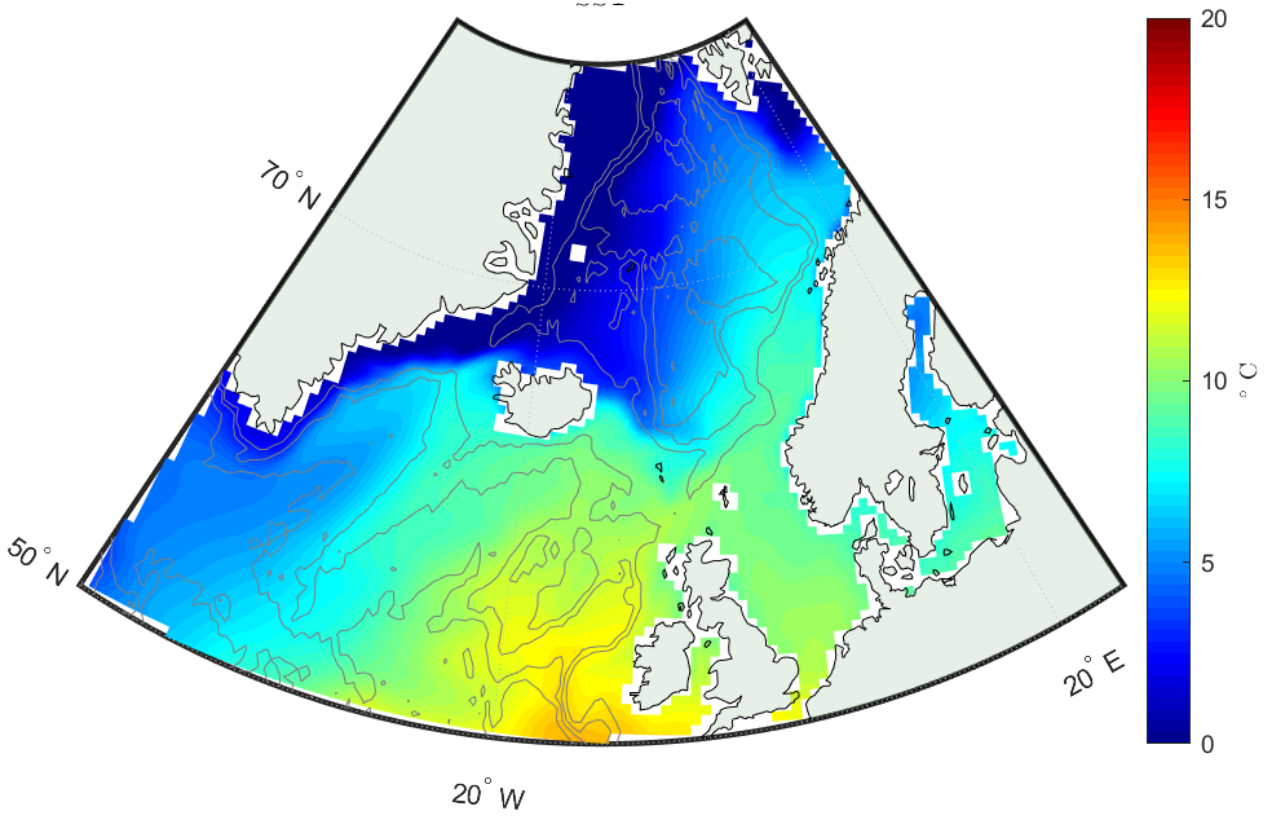


Nordic Seas SST

Control



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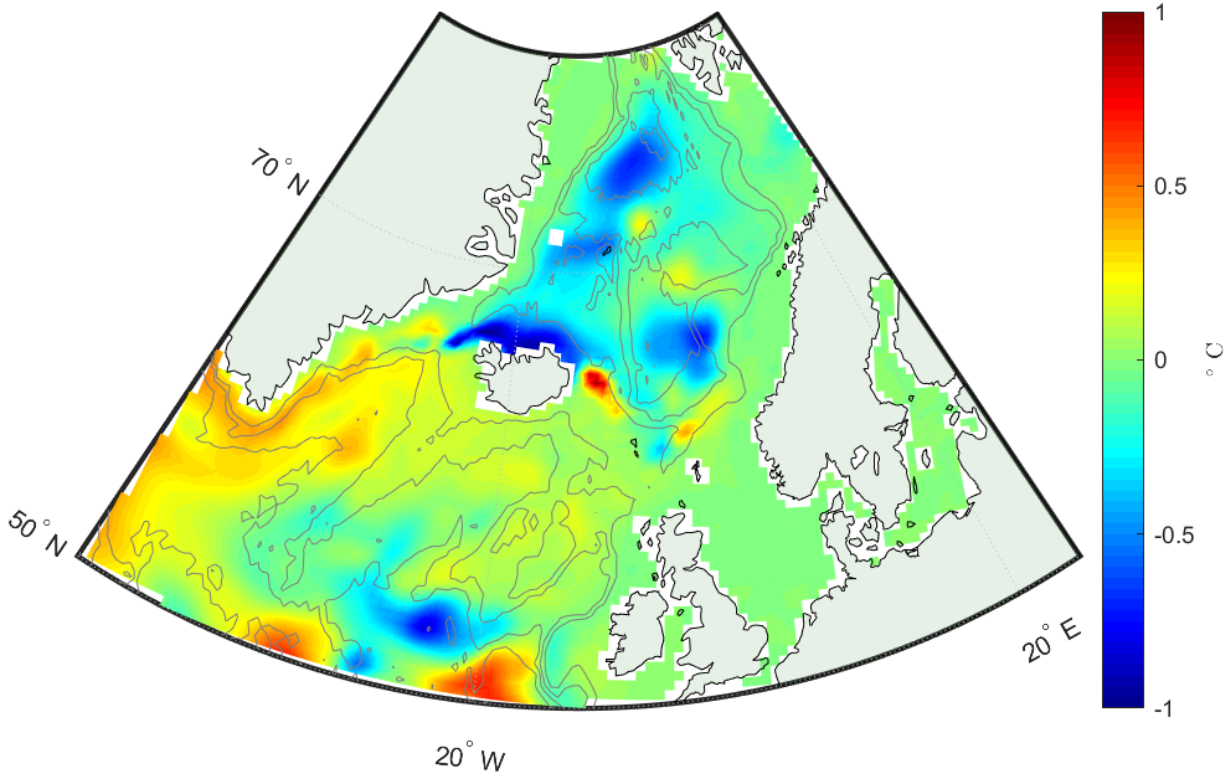
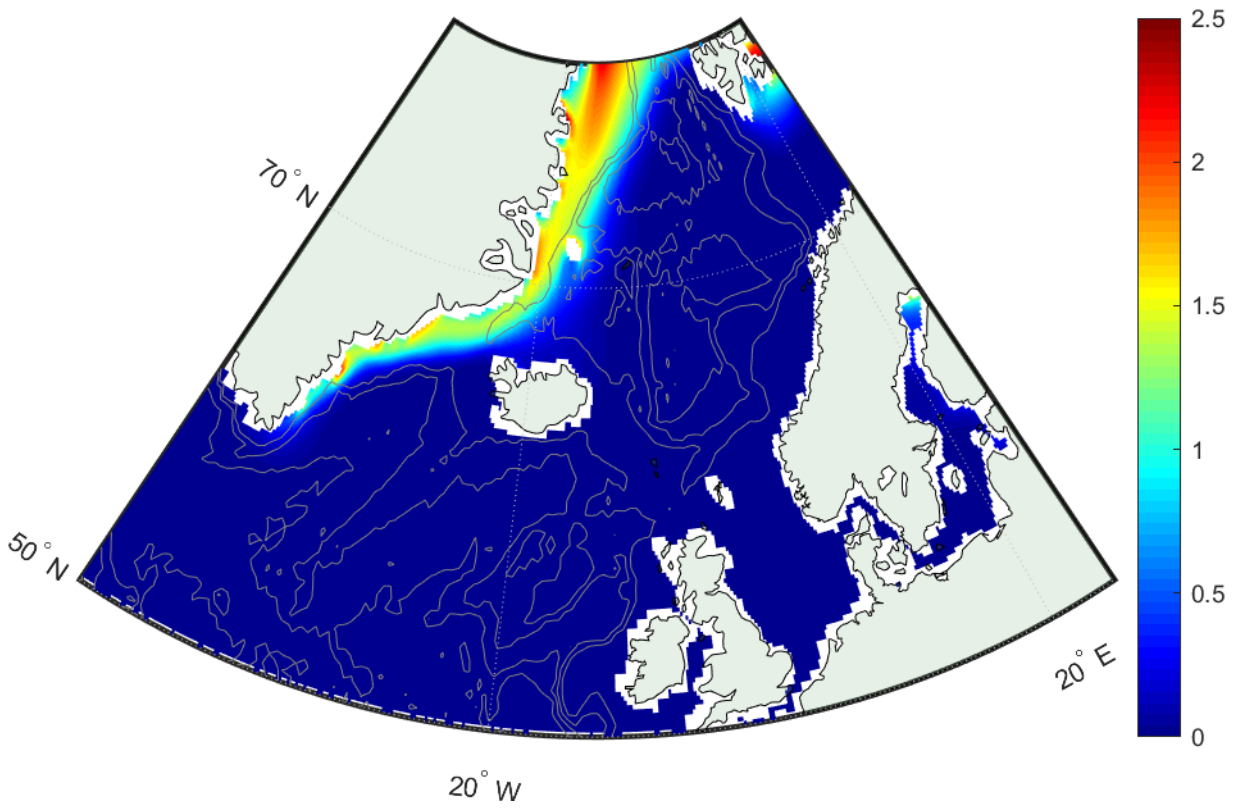


Nordic Seas JFM Sea Ice Thickness

Control



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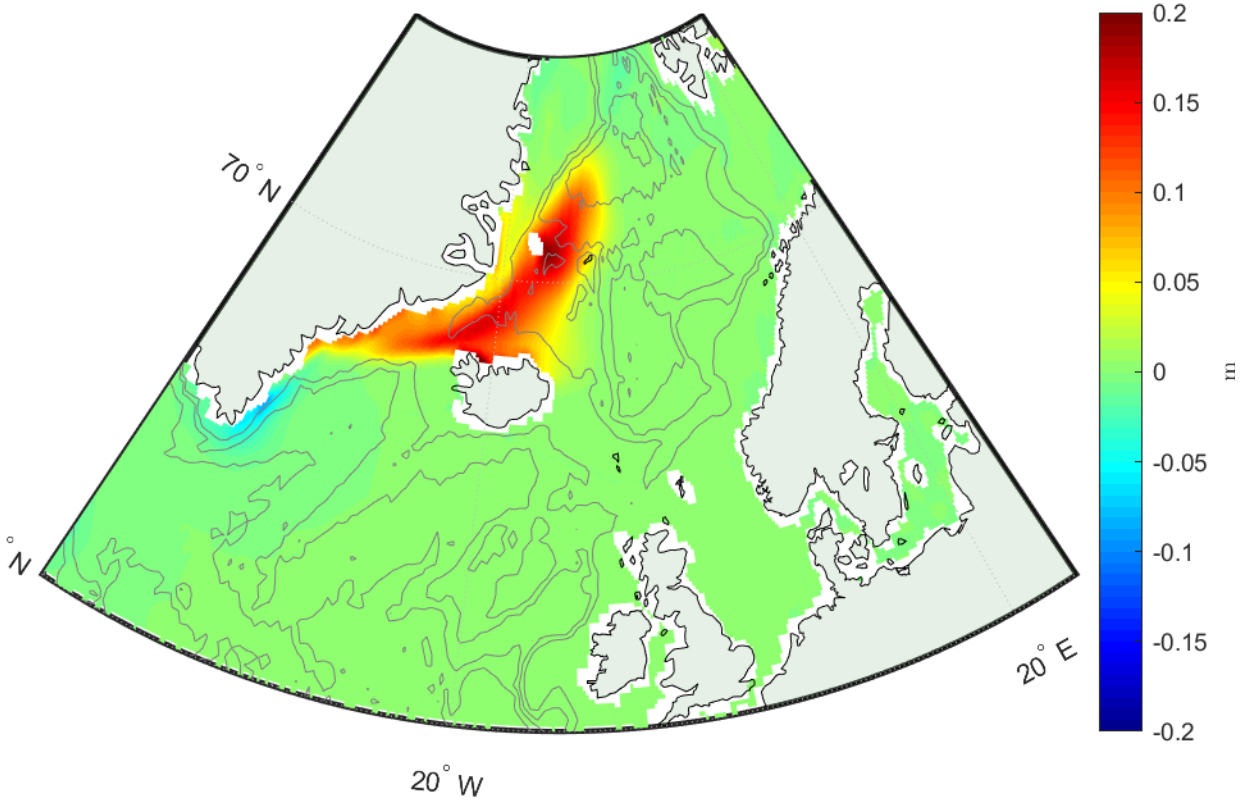
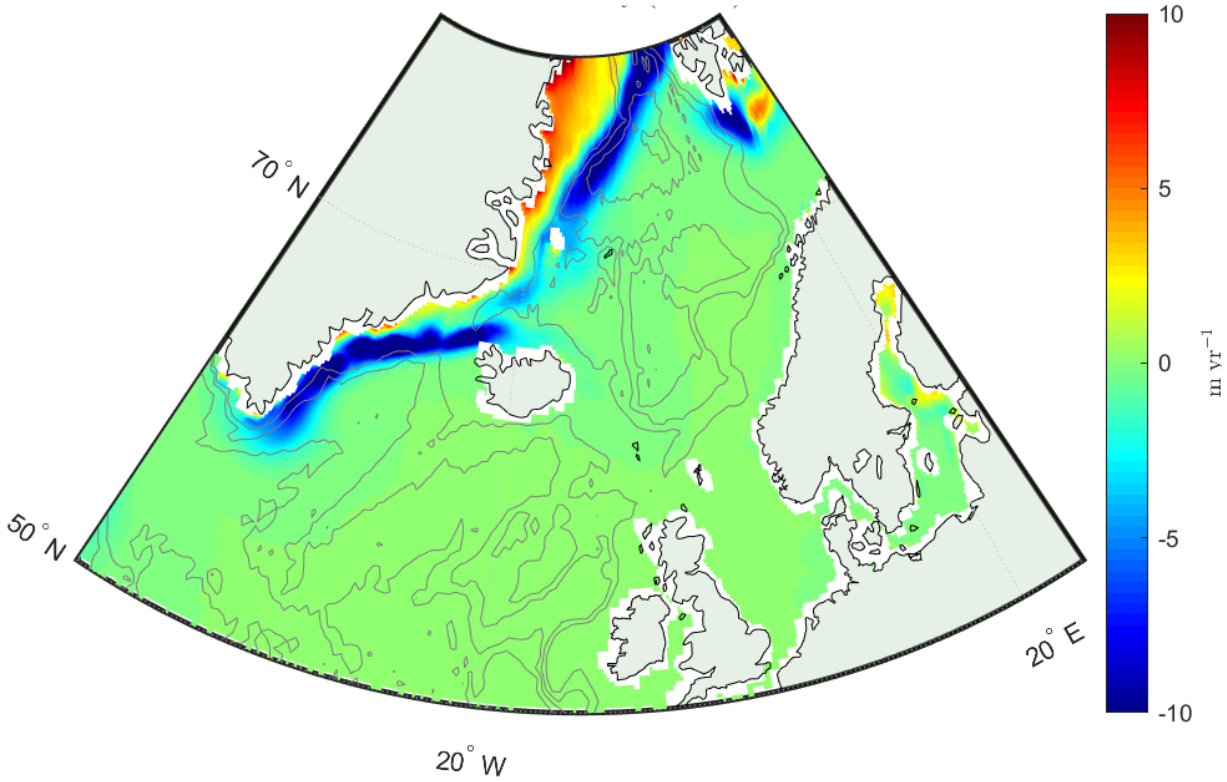


Nordic Seas JFM Sea Ice Growth Rate

Control



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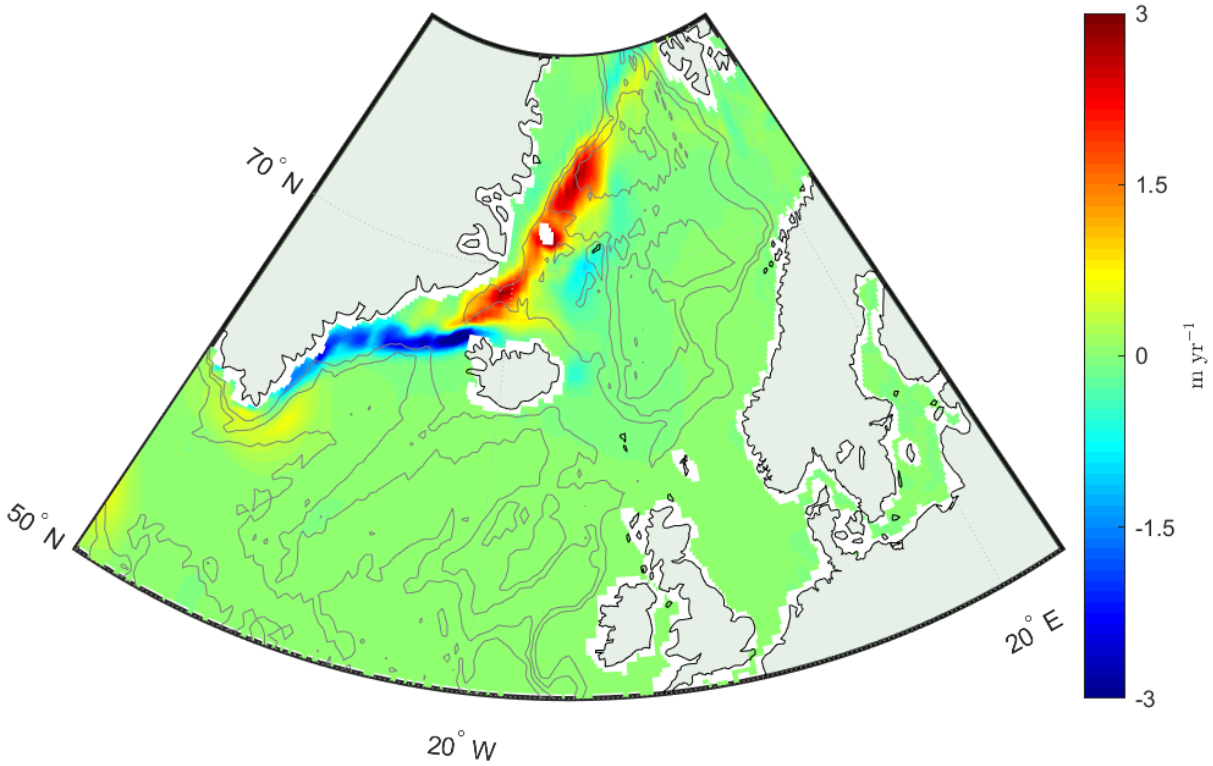


Summary & Conclusions

- Implementing and testing two parameterizations of the unresolved SGS temperature variability in coarse-resolution MOM6 to reduce uncertainties in the horizontal density gradient

- Stochastic parameterization:
  - Increases wintertime MLDs in the Labrador Sea & Southern Ocean
  - Increases MOC transport
  - Increases Global & Atlantic PWT at mid-latitudes; decreases at high latitudes
  - Improves representation of Gulf Stream path
  - Leads to cooling & sea ice increase in the Nordic Seas


Extra Slides

Brankart (2013) Stochastic Parameterization

- Stochastic parameterization of ρ in buoyancy force:

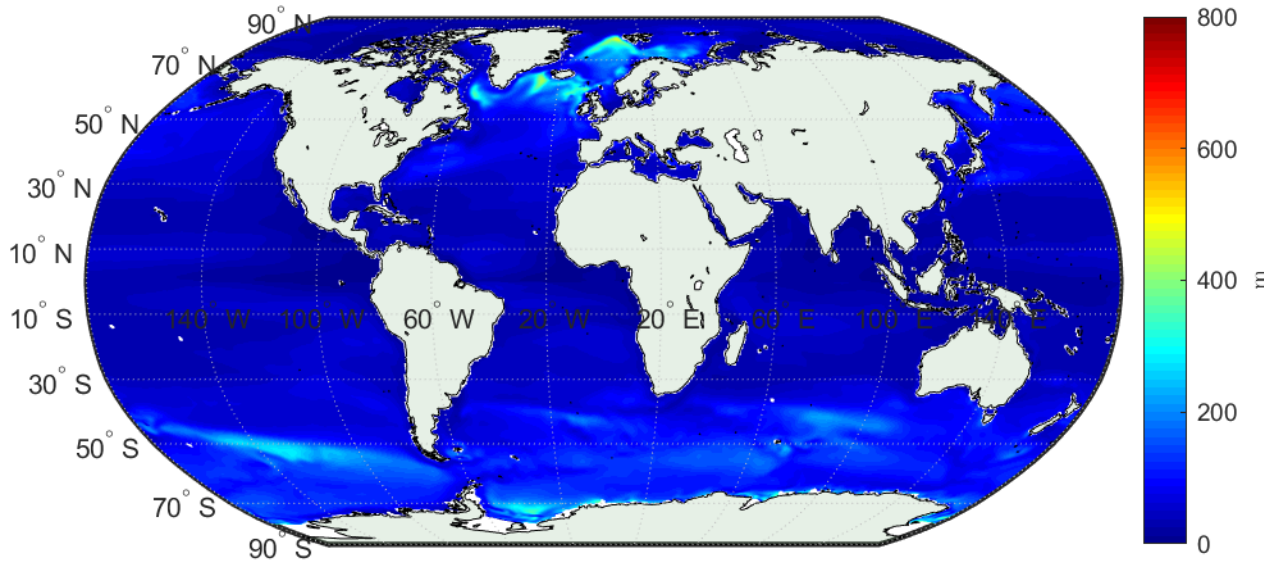
$$\overline{\rho} = \frac{1}{2p} \sum_{i=1}^{p} [\hat{\rho}(\overline{T} + \xi_i \cdot \nabla T, \overline{S} + \xi_i \cdot \nabla S) + \hat{\rho}(\overline{T} - \xi_i \cdot \nabla T, \overline{S} + \xi_i \cdot \nabla S)]$$

- ξ given by an AR-1 process

- Tested in ORCA ~2° horizontal resolution model
- Improved bias in separation latitude of Gulf Stream, Kuroshio Current
- $2p$ evaluations of nonlinear EOS

Winter MLD

Control



deBoyer Climatology