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:
  \[
  \bar{\rho} = \frac{1}{V} \int_G \hat{\rho}(\overline{T} + \Delta T, \overline{S} + \Delta S) \, dx
  \]
  \[
  \bar{\rho} \approx \rho_m + \frac{\partial^2 \hat{\rho}(\overline{T}, \overline{S})}{2} \sigma^2_T
  \]

- See Stanley et al. (2020)
Unresolved SGS Temperature Variability

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

Figure adapted from Stanley et al. (2020)
Potential Density Correction

$\rho$ Correction on $\sim 1^\circ$ Grid Diagnosed from $\sim 0.1^\circ$ POP Model

Figure adapted from Stanley et al. (2020)

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

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

*Brankart (2013): A stochastic parameterization improves WBC separation, SSH field*
Stanley (2020)  
Parameterizations of SGS T Variance  

- Deterministic parameterization:

\[ \sigma_T^2 \approx c |\delta x \circ \nabla T|^2 \]

- Stochastic parameterization:

\[ \sigma_T^2 \approx c e^\chi |\delta x \circ \nabla T|^2 \]

- \( \chi \) given by an AR-1 process

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

- MOM6 + CICE 5
- Global domain
- ~0.66° horizontal resolution
- 65 z* vertical layers
- Branch from existing “best” simulation

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<tr>
<th>#</th>
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<th>Description</th>
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<td>7</td>
<td>Stoch GM</td>
<td>Stochastic GM Only</td>
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</tbody>
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Winter (JFM/JAS) Mixed Layer Depth

Control

Winter (JFM/JAS) MLD Change

Expt - Control
Global Overturning Streamfunction

Control

Expt - Control

Thanks to Gustavo Marques for visualization tools
Gulf Stream Path – Potential Temperature (400 m)
Meridional Heat Transport

Control

Expt - Control

Thanks to Gustavo Marques for visualization tools


Nordic Seas SST

Control

Expt - Control
Nordic Seas JFM Sea Ice Thickness
Nordic Seas JFM Sea Ice Growth Rate

Control

Expt - Control
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 $\rho$ in buoyancy force:

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

- $\xi$ 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