Impact of parameterized submesoscales in a Forced Ocean Sea-Ice simulation

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Ocean-model comparison protocols

**CORE I**: 500-year long simulations forced by 1-year repeating forcing (Griffies et al., 2009)

**CORE II**: Simulations forced by 60-year forcing cycles with interannual variability (Danabasoglu et al., 2014, 2016)

**OMIP-1**: Similar to **CORE II** but with 61-year cyclic JRA55 forcing (Griffies et al., 2016)

**OMIP-2**: Similar to **OMIP-1** but with JRA55-do forcing (Chassignet et al., 2016)

(and many others)
FOSI: Forced Ocean Sea-Ice experiment

Similar to OMIP-2
Atmospheric forcing and river runoff from 61-year cyclic JRA55-do reanalysis

Ocean model: POP (Parallel Ocean Program)
Ice model: CICE (Los Alamos)
Nominal ocean resolution: 0.1 deg (62 levels)

Initial $T$, $S$: January climatology from WOA
Initial velocity: At rest
FOSI: Forced Ocean Sea-Ice experiments

Existing hi-res FOSI data: **5 cycles, years 1-305**

- No submesoscale parameterization
- Tuning of sea-ice albedo + restoring of temperature under sea-ice in **5th cycle**
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Present work: Simulate ~1 FOSI cycle with submesoscale parameterization

Frontal length scale = 5 km

Branch run from year 0245
54 years completed (1958-2011)

Fox-Kemper et al. (2008)
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Output: monthly fields

Analysis period: Years 16-54

Fox-Kemper et al. (2008)

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Output: Monthly fields

Fox-Kemper et al. (2008)

The MLE parameterization of Fox-Kemper et al. (2008b) is given by

$$\Psi_0 = C_e \frac{H^2 \nabla b^z \times \hat{z}}{|f|} \mu(z),$$

(5)

$$\mu(z) = \max \left\{ 0, \frac{1}{\left[ \left( \frac{2z}{H} + 1 \right) \right]^2} \left[ 1 + \frac{5}{21} \left( \frac{2z}{H} + 1 \right)^2 \right] \right\}.$$

where $H$ is mixed layer depth, $f$ is the Coriolis parameter, and $\hat{z}$ is the unit vertical vector. The subscript $0$ is to indicate that this is the original form appropriate for extratropical, mesoscale-resolving models. A modified form appropriate for coarse-resolution global models is given below. The overline with subscript $z$ on $\nabla b^z$ is understood to be the depth-average of $\nabla b$ over the mixed layer. The efficiency coefficient $C_e$ is found to be 0.06-0.08 from MLE-resolving simulations (Fox-Kemper et al., 2008b).

An adaptation to (5) that is suitable and justified in a global coarse-resolution model is

$$\Psi = C_e \frac{\Delta s}{L_f} \frac{H^2 \nabla b^z \times \hat{z}}{\sqrt{f^2 + \tau^2}} \mu(z).$$

(6)

Frontal length scale = 5 km

Analysis period: Years 16-54
MOC averaged between 2004–2011
Mixed-layer definition: Shallowest depth where local $N^2$ matches bulk $N^2$ referenced to the surface

$\Delta$: $\text{FOSI}_{\text{subm}} - \text{FOSI}_{\text{nosubm}}$
Globally averaged SST

FOSI_{nosubm}
2.2. General Structure of the KPP Parameterization

For any prognostic scalar or vector field component $\psi$ (e.g., tracer concentration and velocity component), the KPP scheme parameterizes the turbulent vertical flux within the surface boundary layer according to

$$\langle w'\psi' \rangle = -K_\psi \frac{\partial \psi}{\partial z} + K_{\psi'} \psi', \quad (5)$$

where $\psi'$ represents the subgrid scale fluctuation relative to $\psi$. The first right-hand side term represents the local contribution to the turbulent vertical flux of $\psi$, and the second term is the parameterized nonlocal flux. The eddy diffusivity $K_\psi$ is written as the product of three terms

$$K_\psi = h w_\psi(\sigma) G(\sigma), \quad (6)$$

Van Roekel et al. (JGR, 2018)

Plot on the previous slide is the negative divergence of this term.
Globally averaged heat budget

FOSI_{subm}
Globally averaged heat budget

![Graph showing heat budget with depth and temperature changes.](image-url)
Resolved eddy advection

\[ -\nabla \cdot (\mathbf{u}'T')_{\text{res}} \text{ at 5 m depth} \]

Submesoscale temperature tendency

\[ -\nabla \cdot (\mathbf{u}'T')_{\text{res}} \text{ at 5 m depth} \]

Submesoscale temperature tendency at 5 m depth

\[ -\nabla \cdot (\mathbf{u}'T')_{\text{res}} \text{ at 5 m depth} \]

Submesoscale temperature tendency at 5 m depth

\[ -150 -100 -50 0 50 100 150 \]

\[ -150 -100 -50 0 50 100 150 \]

\[ -150 -100 -50 0 50 100 150 \]

\[ -150 -100 -50 0 50 100 150 \]
Eddy vertical heat flux

\[ \langle w'T' \rangle = \langle wT \rangle - \langle w \rangle \langle T \rangle \]
R-CESM: WRF + ROMS coupled simulation of the North Pacific at 3 km resolution

Fu et al. (BAMS, 2021)
Eddy vertical heat flux

Kuroshio

Gulf Stream

Depth (m)

Eddy heat flux (W/m²)

Flux convergence (°C/year)
In a 0.1° FOSI run, the contribution from parameterized submesoscales to the temperature tendency is comparable to that from resolved eddy advection.

Repartitioning of resolved and submesoscale heat flux to yield nearly the same total flux in the upper ocean

Necessary to explore the impact of new models for the frontal length scale $L_f$ (Bodner et al., 2021) in 0.1° POP