Internal Wave Modeling in Oceanic General Circulation Models

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Introduction

• One of the main internal wave generation mechanism is the interaction of the barotropic tide with rough topography.

• Dissipation is through internal wave breaking.

• The global ocean circulation is sensitive to this tidally driven mixing (Simmons et al., 2004).

• In OGCMs, internal waves are only partially resolved.

• Internal wave breaking mixing needs to be parameterized in hydrostatic OGCMs.

• In ‘fixed’ coordinate ocean models, internal waves generate a spurious diapycnal mixing which has not yet been quantified and could be quite large.
Motivation

Derivation a physically-based tidal mixing parameterization as a function of resolvable properties (shear, stratification, low wave modes)

Evaluation of OGCMs on simulating these resolvable properties
A. Investigation of internal waves’ representation in OGCMs as a function of model grid spacing (Direct Numerical Simulation to climate models)

B. Documentation of the numerically-induced mixing in ‘fixed’ vertical coordinate ocean models (σ- and z-levels)
A. Internal wave representation in OGCMs

- Comparison of analytical solutions (Khatiwala, 2003; St. Laurent, 2003) and numerical simulations (HYbrid Coordinate Ocean Model, HYCOM, and the Regional Ocean Modeling System, ROMS).

- Diagnostics: Baroclinic response and energy fluxes (tidal conversion) for $\Delta x = [0.25, 0.75, 1.5, 5, 10, 30, 100]$ km and number of vertical coordinates = [2, 5, 10, 25, 45, 100].
Analytical vs. Numerical simulations

Snapshot of cross-vertical section of $U$ baroclinic velocity $\Delta x = 1.5$ km

Analytical (T=114h)  HYCOM (T=113.75h)  ROMS (T=113.5h)

- Phase error: After ~4 simulation days, ROMS is ~30 min faster and HYCOM is ~15 min faster when compared to the analytical solution.
- In ROMS, the numerically-induced mixing changes the stratification and thus can change the dynamic of the internal wave. What is the contribution of the spurious mixing to the wavelength and phase errors?
B. Quantifying the spurious mixing in ROMS

- No mixing prescribed
- Volume of water masses should be time invariant.
- Loss of volume in density intervals is only due to a numerically induced mixing.
- Intervals are taken every 0.0001 kg/m³

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- Analytically, the change in vertical stratification due to the spurious mixing accounts for less than a kilometer in the wavelength error (not even a grid point).
- Over a long time period, the spurious mixing will lead to an homogeneous water column → equivalent diffusivity to be quantified.
Critical and super-critical wave regime

Results

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HYCOM Sensitivity studies

- To the deformation-dependent Laplacian viscosity factor (visco2)

Snapshot of cross vertical section of the zonal baroclinic field

**HYCOM 1.5 km**

- Viscosity = 0
- Viscosity = 5e-2
- Viscosity = 1e-4
- Viscosity = 5e-1
Impact of the model resolution

Results

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- If model grid spacing length is < 2 km, representation of the internal wave field similar in both models.
- Inability to represent the higher wave modes as the grid spacing approaches 5 km.
- Pressure gradient error in ROMS appears when the topography is under resolved. Topography smoothing is necessary.
- Bump = 20 km
Energy fluxes for a 600 m bump

- Non dimensional depth integrated energy fluxes at the tip of the ridge from the ‘knife-edge’ analytical solution (St. Laurent et al., 2003).
- This method gives the energy contained in each wave mode number

\[
\begin{align*}
\text{Analytical} & \quad \text{HYCOM} & \quad \text{ROMS} & \quad \text{‘Unresolved’ wavelength} \\
\Delta x = 0.75 \text{ km} & \quad \Delta x = 1.5 \text{ km} & \quad \Delta x = 5 \text{ km} & \quad \Delta x = 10 \text{ km}
\end{align*}
\]

- Above the tip of the ridge, HYCOM has only 17 layers and thus resolve fewer vertical wave modes than ROMS (45 layers)
Future work

- More sensitivity studies with HYCOM and ROMS
- Same simulations with a wider bump to go to coarser resolution
- Same simulations with the hydrostatic and non-hydrostatic capability of the MITgcm (DNS)

Hydrostatic MITgcm
1.5 km resolution
Snapshot zonal baroclinic velocity field

- Same simulations with the new NCOM vanishing sigma-grid