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

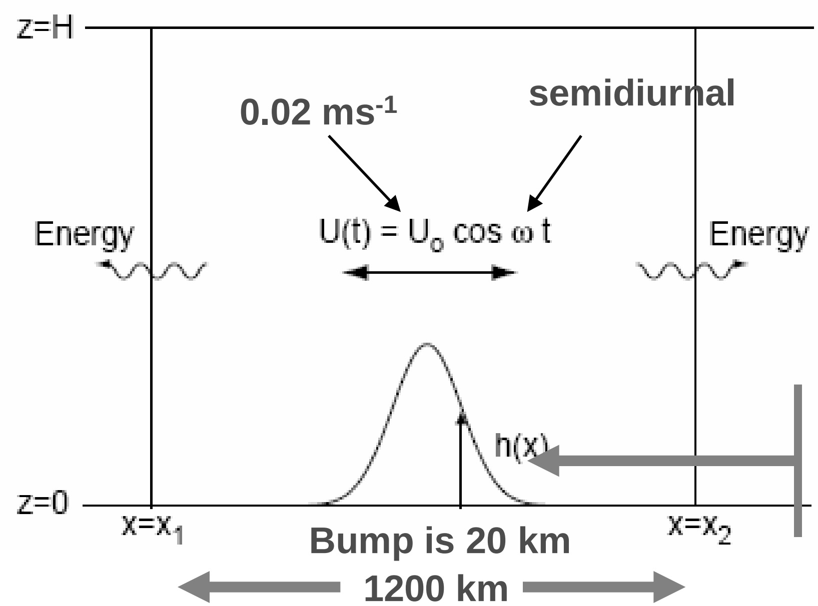
Goals

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).



- No Coriolis
- Uniform stratification (linear equation of state)
- Non-reflecting open boundaries (Flather)
- Free slip boundary conditions
- Output saved every 15 minutes

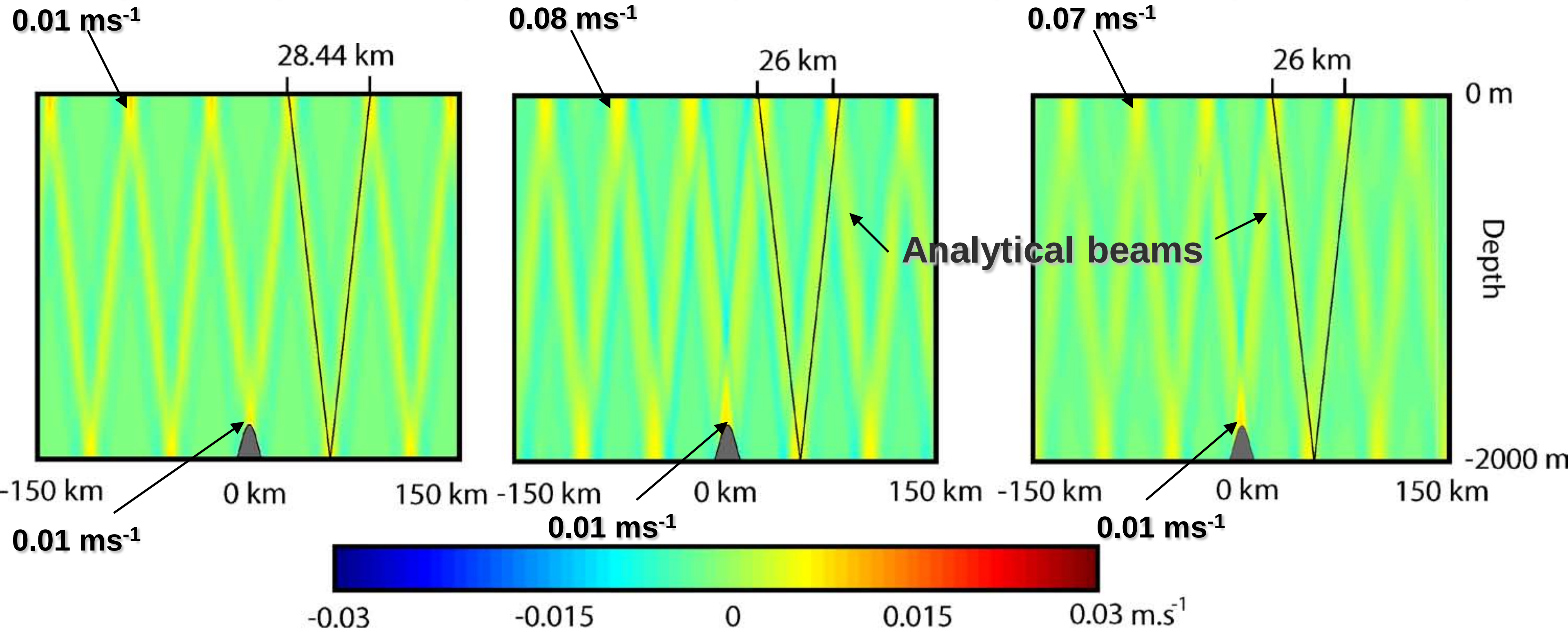
If *max($h_{(x)}$)* < 300 m, subcritical wave regime
If 300 < *max($h_{(x)}$)* < 500 m, critical wave regime
If *max($h_{(x)}$)* > 500 m, supercritical wave regime

- Diagnostics: Baroclinic response and energy fluxes (tidal conversion) for *Δx = [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 Δx = 1.5 km

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

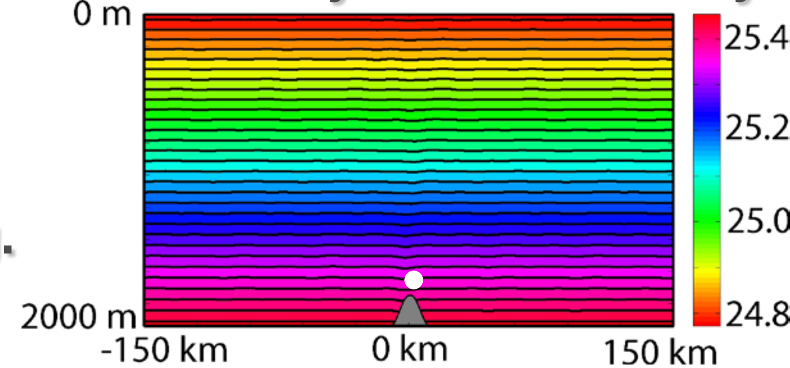


- Phase error: After ~4 simulation days, ROMS is ~30 min faster and HYCOM is ~15min faster when compared to the analytical solution.
- In ROMS, the numerically-induced mixing changes the stratification and thus can change the dynamic of the internal wave. **What is the contribution of the spurious mixing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

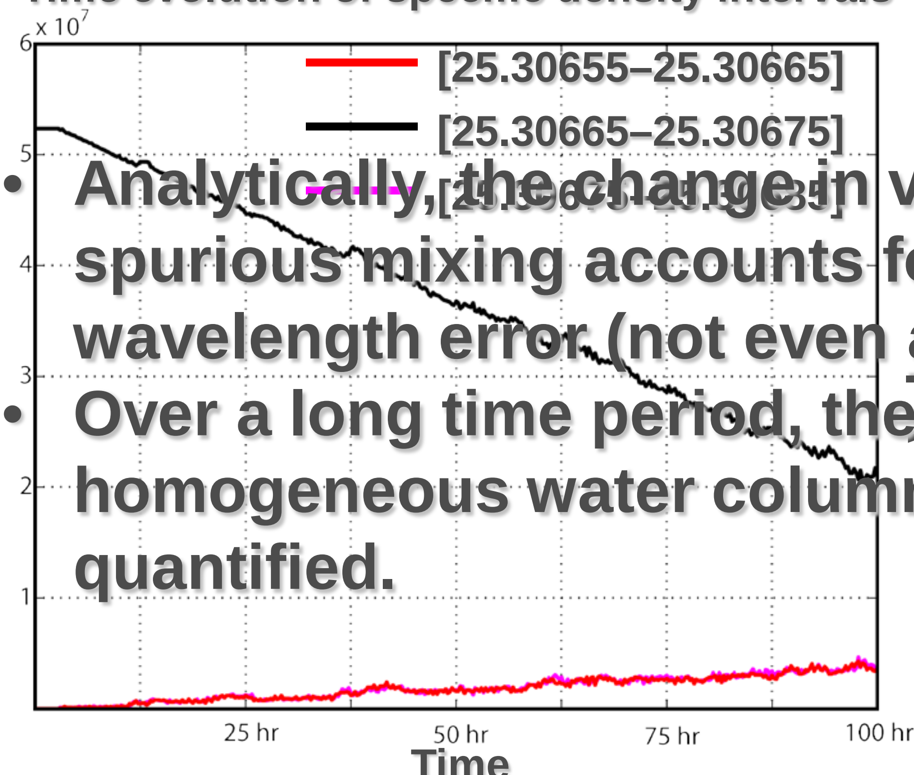
B. Quantifying the spurious mixing in ROMS

- 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

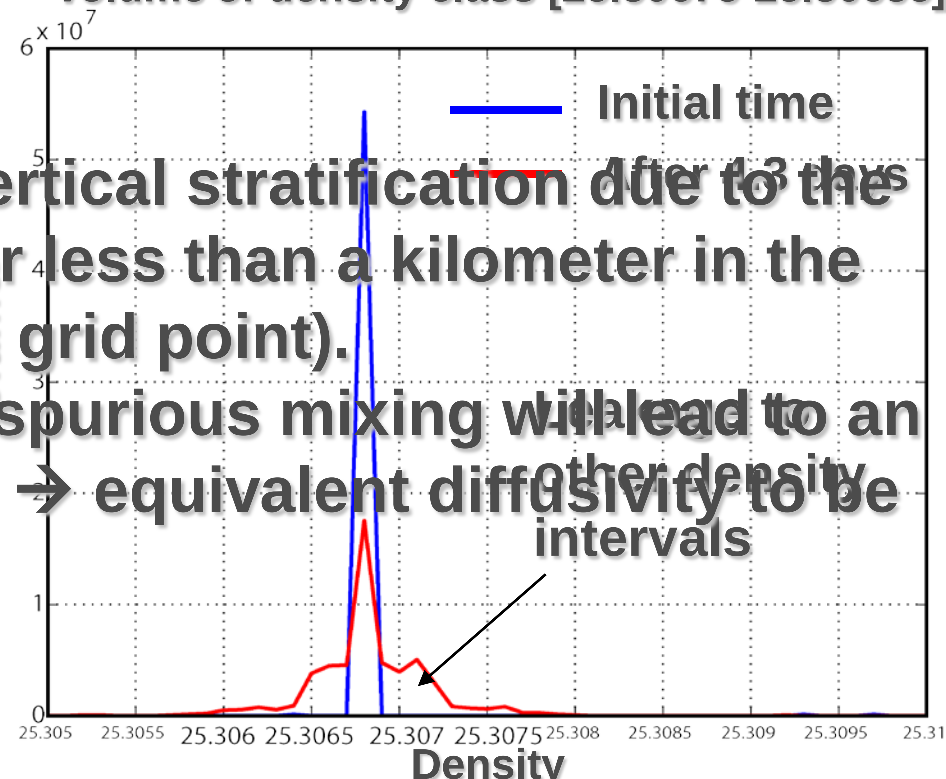
ROMS density field after 4.3 days



Time evolution of specific density intervals

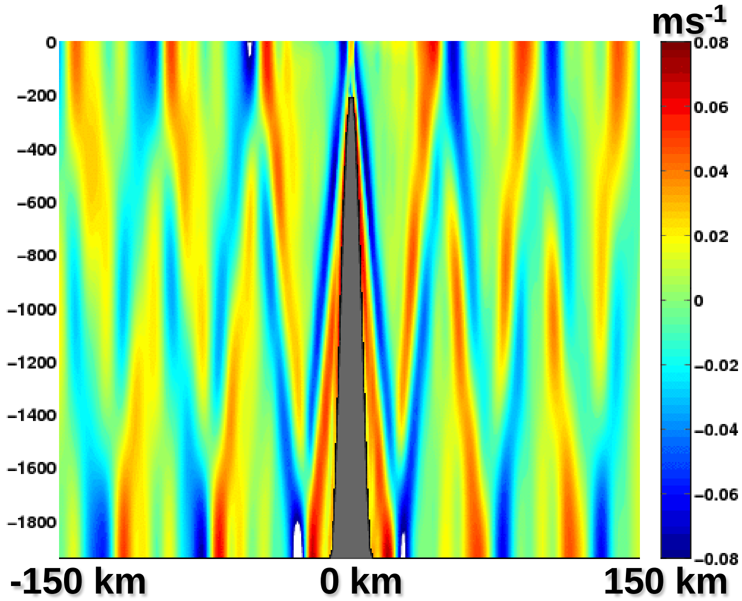


Volume of density class [25.30675-25.30685]



- 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.

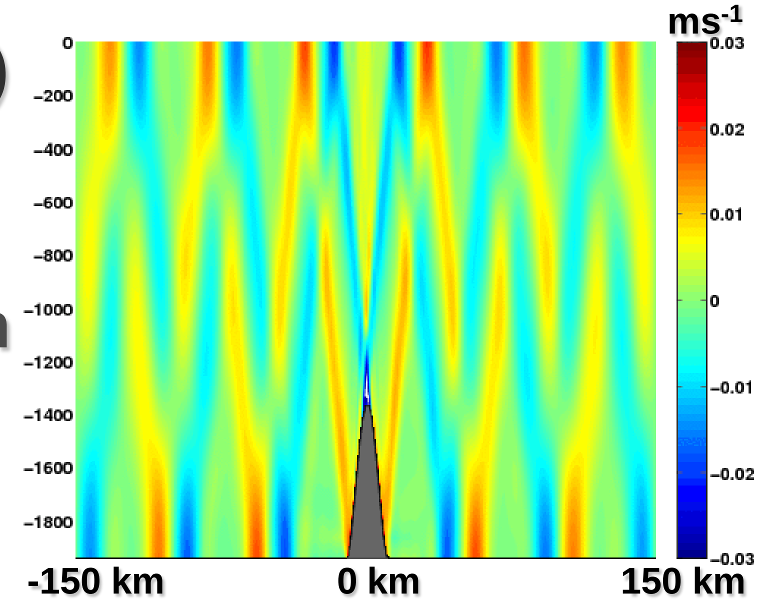
Critical and super-critical wave regime

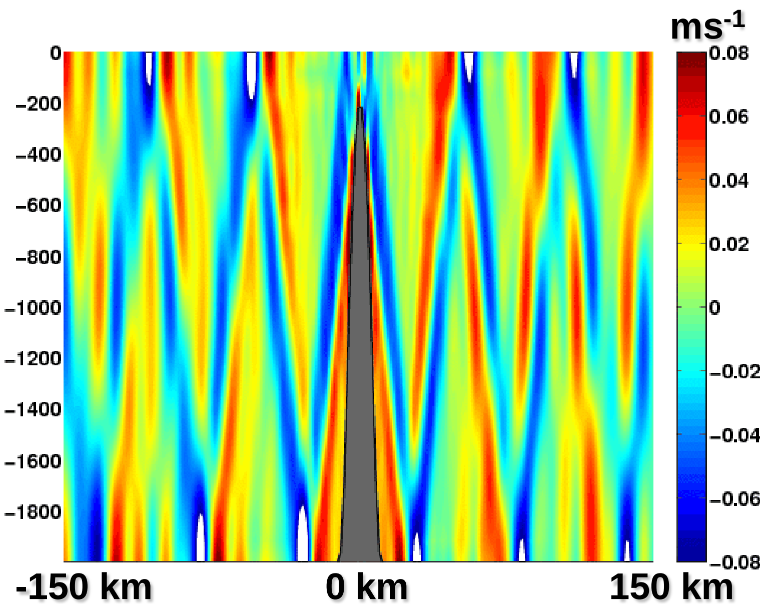


(animation)

ROMS

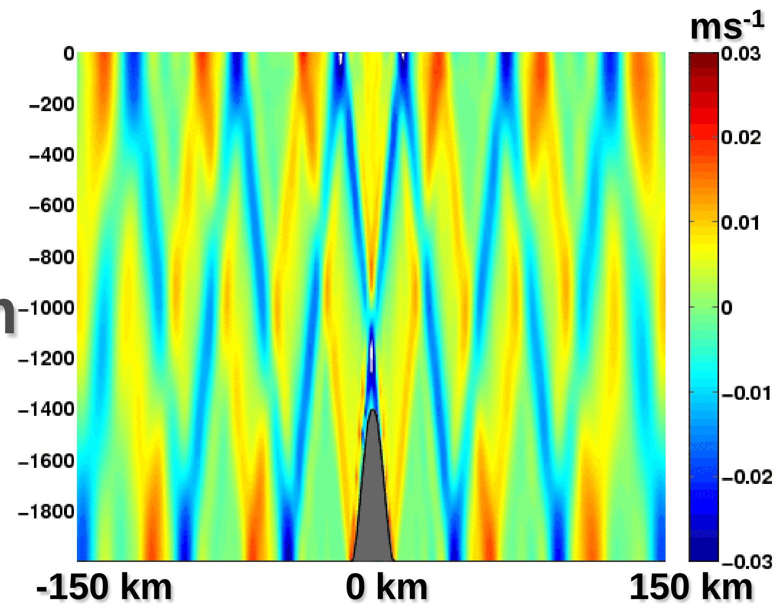
Δx = 1.5 km





HYCOM

Δx = 1.5 km

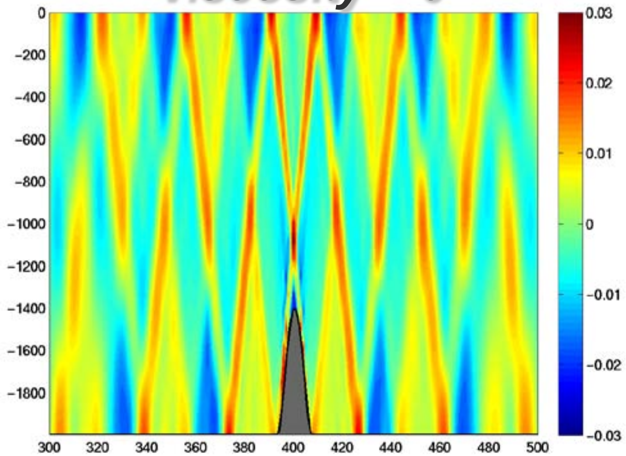


HYCOM Sensitivity studies

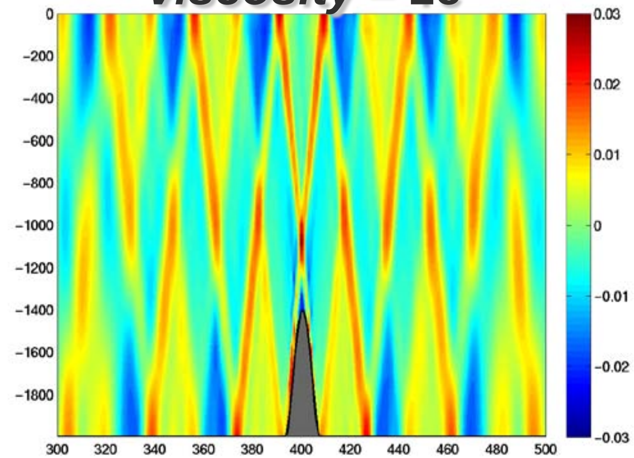
- **To the deformation-dependent Laplacian viscosity factor (*visco2*)**
  Snapshot of cross vertical section of the zonal baroclinic field

HYCOM 1.5 km

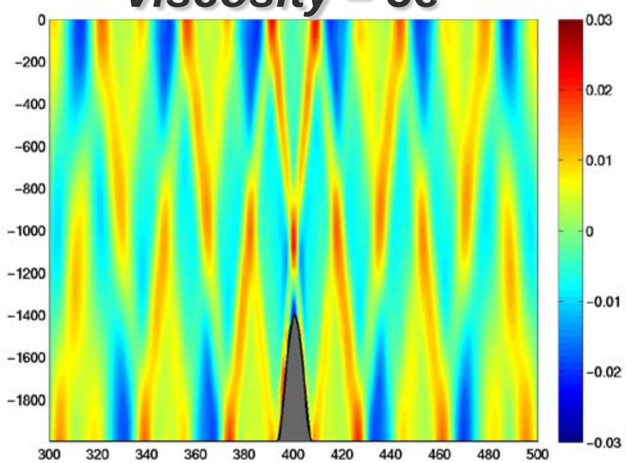
***Viscosity* = 0**



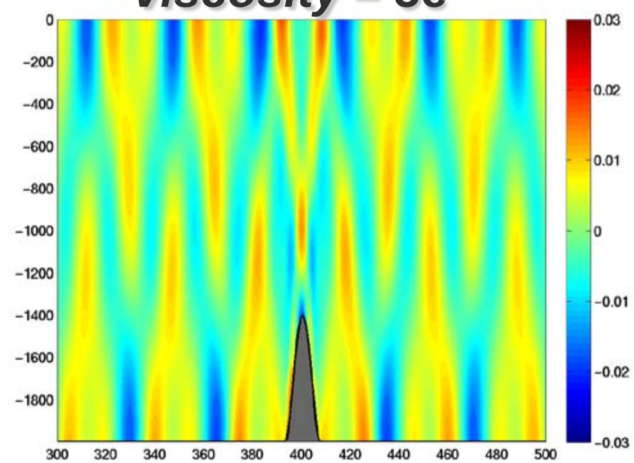
***Viscosity* = 1e^{-4}**



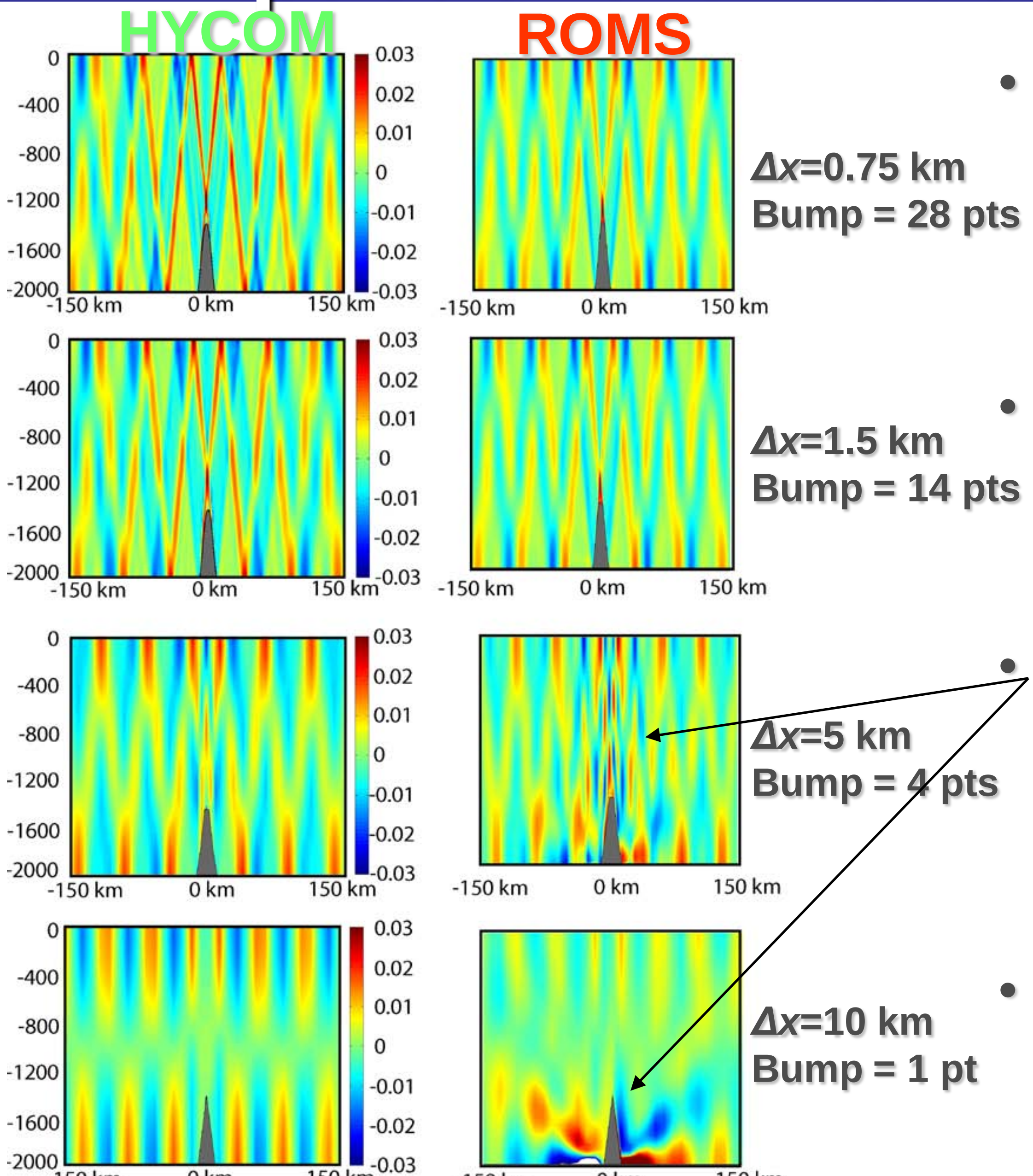
***Viscosity* = 5e^{-2}**



***Viscosity* = 5e^{-1}**



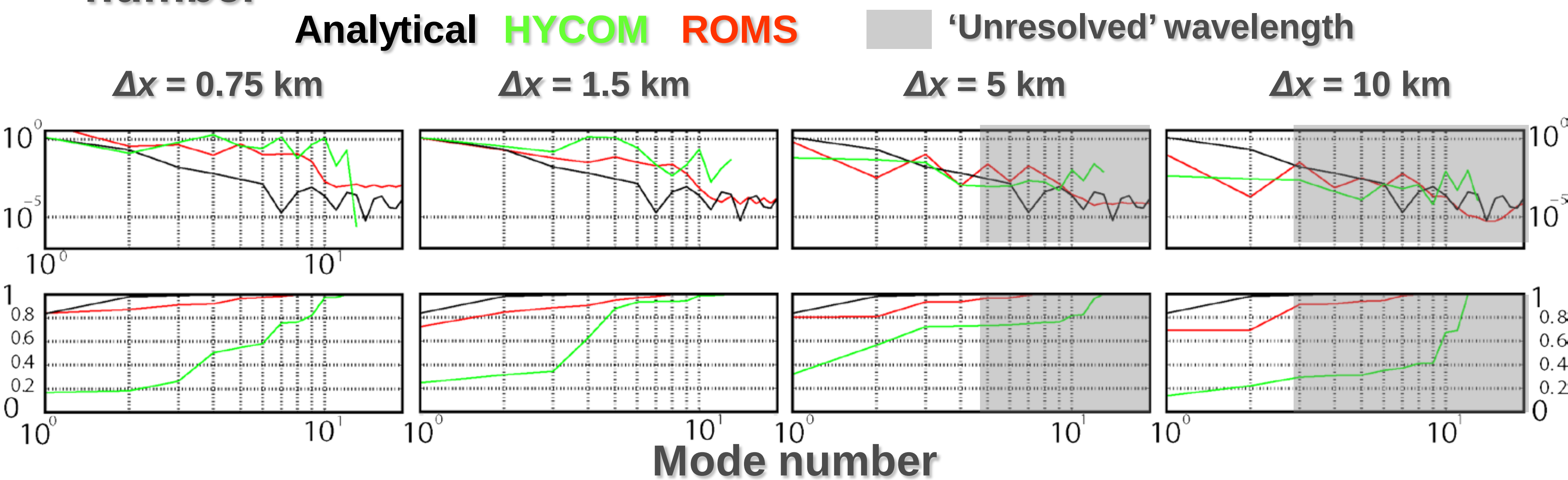
Impact of the model resolution



- 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

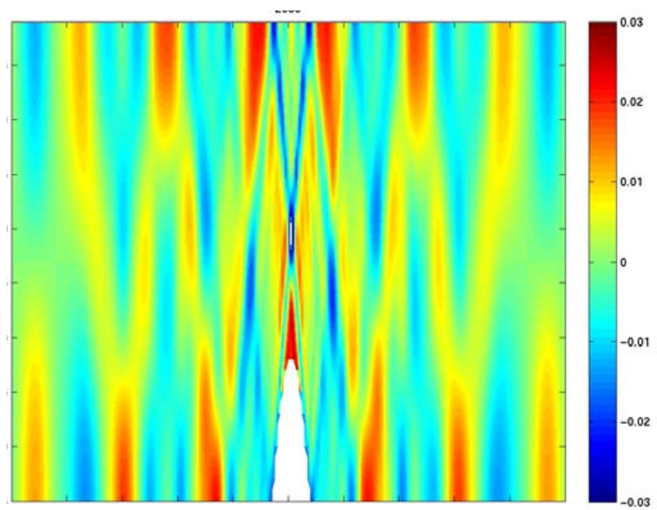


- Above the tip of the ridge, HYCOM has only 17 layers and thus resolve fewer vertical wave modes than ROMS (45 layers)

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