Vertical Tidal Mixing in ROMS: A Reality Check

Dr. Robin Robertson
School of PEMS
UNSW@ADFA
Canberra, Australia
Adjunct at
Lamont-Doherty Earth Observatory of Columbia University
Vertical Tidal Mixing

• Internal Tides = significant mixing mechanism
  - 3.2 TW (TW=10^{12} W) [Garrett, 2003]

• Measurements
  - Difficult and expensive
  - Small scale ..... Hard to locate
  - Episodic ......... Harder to be there at right time

• From Models
  - Model needs to reproduce the energy transfers from the tides to dissipation
  - Depends on the vertical mixing parameterization used
  - Need high resolution and good bathymetry
Why get Vertical Mixing Right?

Important for:

- Water mass formation and transformation
  - Indonesian Throughflow
  - Polar regions
- Structure of the water column
- Biological studies
- Diffusion of momentum
- Non-linear wave interactions
- ...

Location of INSTANT Moorings
$M_2$
Internal Tides for Transect across the INSTANT Moorings
A Region of Inactive/Background Internal Tides

- Model spectrum match of that the observations
  - within 90% confidence levels for 0.02-0.33 cph
- Differ at high and low frequency ends
- Energy levels match Garrett-Munk (dashed green line (N=20 cph))
A Region of Active Internal Tides

- Harmonics peak up for both the **model** and the **observations** (red and black)

- Energy levels above Garrett-Munk (dashed green line at high frequencies)

- Differ at high and low frequency ends
Vertical Mixing Parameterizations In ROMS

- Mellor-Yamada 2.5 level turbulence closure (MY2.5)
- Kpp – Large-McWilliams-Doney (LMD)
- Brunt-Väisälä Frequency Based (BVF)
- Pacanowski-Philander (PP)
- General Ocean Mixing (GOM)
- Generic Length Scale (GLS)
  - $\kappa$-$\omega$
  - $\kappa$-$\varepsilon$
  - $\kappa$-$\kappa_l$
  - Generic -old
  - Generic -new
Fieberling Guyot

Water Depth

Latitude

Longitude

F2, F2, P
F4, F5

B2

B3

R3

R2

P

Water Depth (m)
Evaluated the Performance of these Mixing Parameterizations

- Internal Tidal model for Fieberling Guyot
- Accessible data set for both velocities and dissipation
- Good agreement for major axes of semidiurnal tidal ellipses between model estimates and observations
Semidiurnal Tidal Velocity Dependence: Vertical Mixing Parameterization.
Diffusivity of Temperature: Vertical Mixing Parameterization

Observations ($K_\rho$) from Kunze and Toole (1995; 1997)
### Vertical Diffusivities Averaged over the Region

- **MY25**\(^*\) $\quad 1.4 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **GOM** $\quad 9.0 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$
- **BVF** $\quad 1.3 \times 10^{-2} \text{ m}^2 \text{ s}^{-1}$ (way too big)
- **LMD**\(^*\) $\quad 1.1 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **LMD-SCCW** $\quad 1.0 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **PP** $\quad 8.0 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ (too small)
- **GLS- kkl** $\quad 3.8 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **GLS- k\(\omega\)** $\quad 3.7 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **GLS- k\(\varepsilon\)^*\) $\quad 1.9 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **GLS- gen\(^*\)** $\quad 1.8 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$
- **GLS- gen2\(^*\)** $\quad 3.7 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ (looks best; good value)
Is there really no difference in the velocities?

• Maybe the tidal frequencies aren’t the place to look
• Vertical mixing transfers energy from tides to high frequencies, especially harmonics
Spectral Response

- Background Location
- Follows Garrett-Munk spectra (N=5 cph)
Leads to 2 questions

• Why do the spectra follow Garrett-Munk?
• Which one is the best performer?
Garrett-Munk and Vertical Diffusion

- Vertical Diffusion plays a big role in spectral shape
- Is not responsible for all of the transfer of energy between frequencies or energy cascade
- Does induce non-linear interactions and transfer energy from low to high frequencies
- Does remove the higher frequency energy and contribute to the slope
- Background location
  - Black - with vertical diffusion
  - Red - without vertical diffusion
What about Higher Frequencies?

- Diurnal and Semidiurnal tidal peaks clearly visible
  - 0.04 hr⁻¹ (24 hr)
  - 0.08 hr⁻¹ (12 hr)
- GOM has increased energy at highest frequency (midlevel)
Focusing on Higher Frequencies

- Internal Wave Generation Site
Normalizing by MY25

- Internal Wave Generation Site
Conclusions???

• ROMS can reproduce tidal energy and the harmonics both in regions of active and inactive internal tides (resolution important)
• Vertical mixing parameterizations
  - Correlation between high vertical diffusivity and low spectral energy
  - GOM showed enhanced energy at high frequencies; exceeded the 95% confidence
  - PP shows very weak vertical diffusivity
  - BVF, GLS-kkl, and GLS-κω have high average $K_M$
  - MY25 has bump in energy at high frequency end
  - Differences at tidal frequencies are very minor
  - Small differences occur in high frequencies.
Summary

• All 10 vertical mixing schemes generated spectra roughly following G-M
  - Believed to be due to non-linear interactions and the vertical mixing parameterization

• Best performers are:
  - GLS-gen (new)
  - GLS-\(K\omega\), GLS-gen then MY25, LMD

  - Based on matching
    • tidal velocities
    • Dissipation: both with depth and area average
    • Spectral response of velocities
Still in Search of a Definitive Answer/
Where to go from here

- This study has some shortcomings
  - Done at a low resolution (2km)
  - Done with old version of ROMS

- Presently repeating the analysis
  - 1 km resolution with 60 levels
  - New version of ROMS (2009)
  - Looking at the frequency response of the vertical diffusivity
Questions?