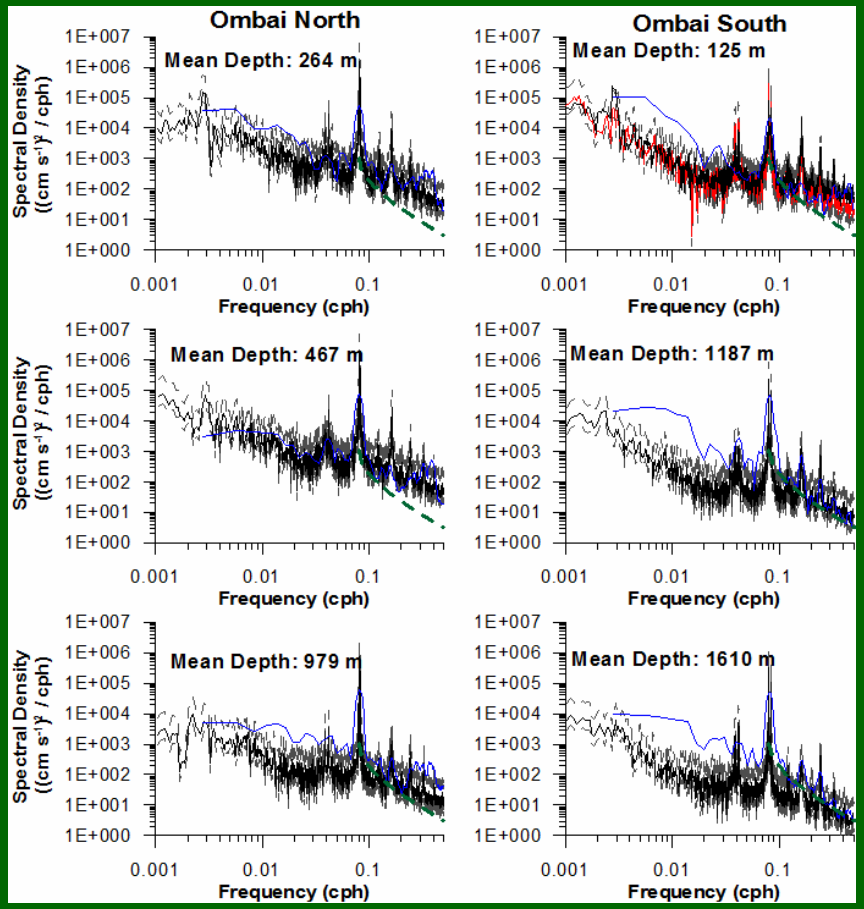
Vertical Tidal Mixing in ROMS: A Reality Check



Dr. Robin Robertson
School of PEMS
UNSW@ADFA
Canberra, Australia

Adjunct at

Lamont-Doherty Earth Observatory of Columbia University

UNSW@ADFA
CANBERRA • AUSTRALIA

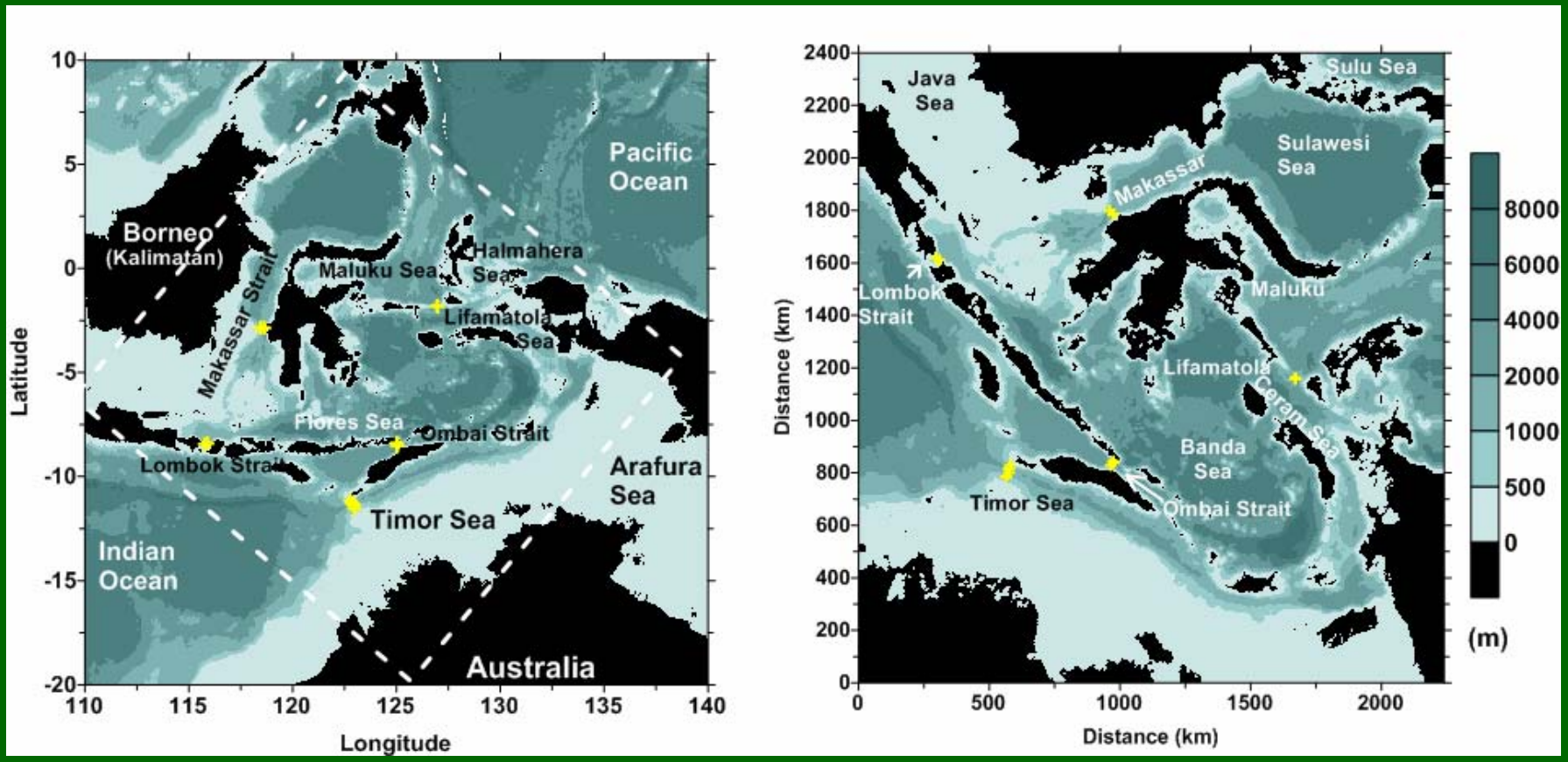
Vertical Tidal Mixing

- 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

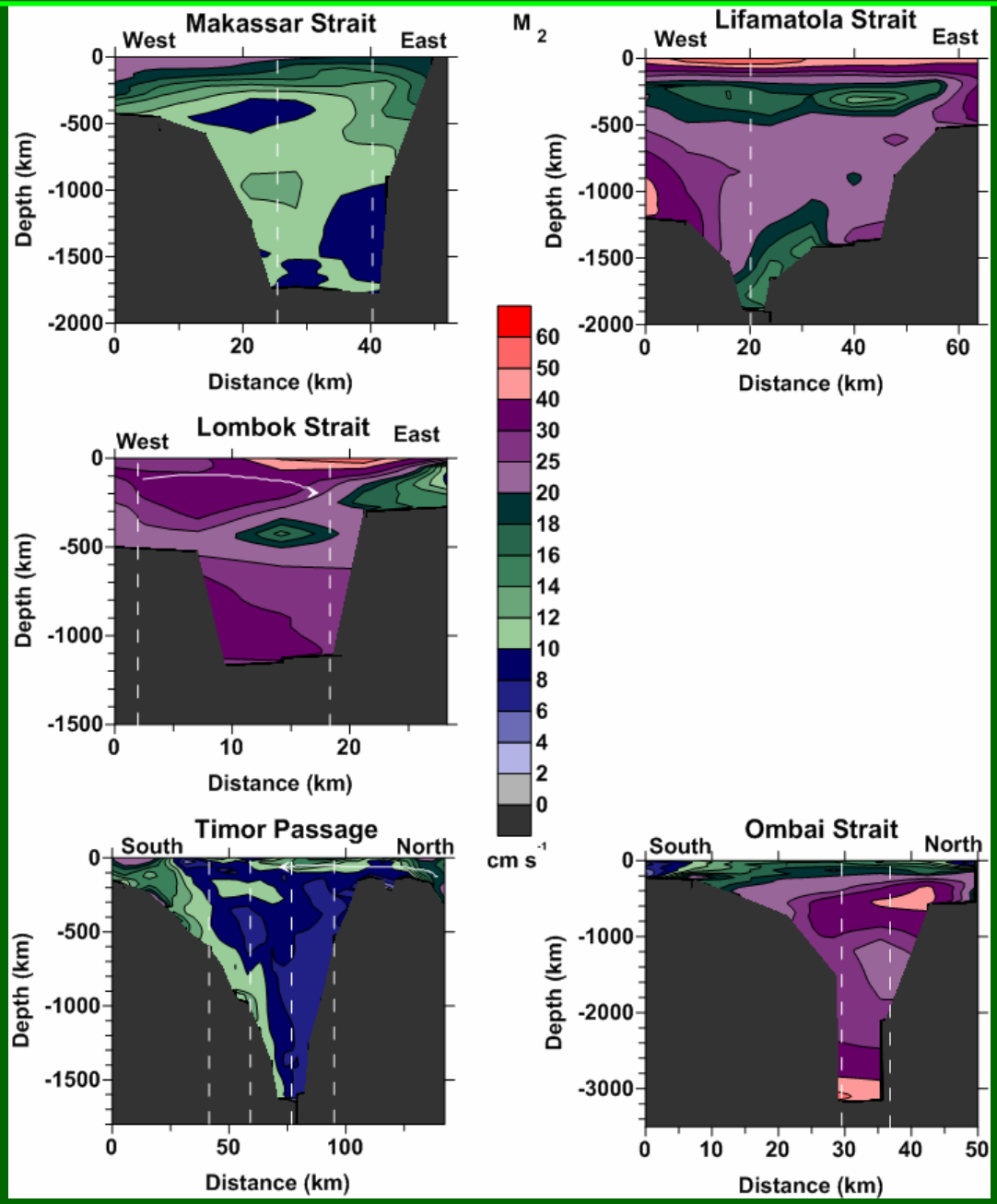
Why get Vertical Mixing Right? Important for:

- 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

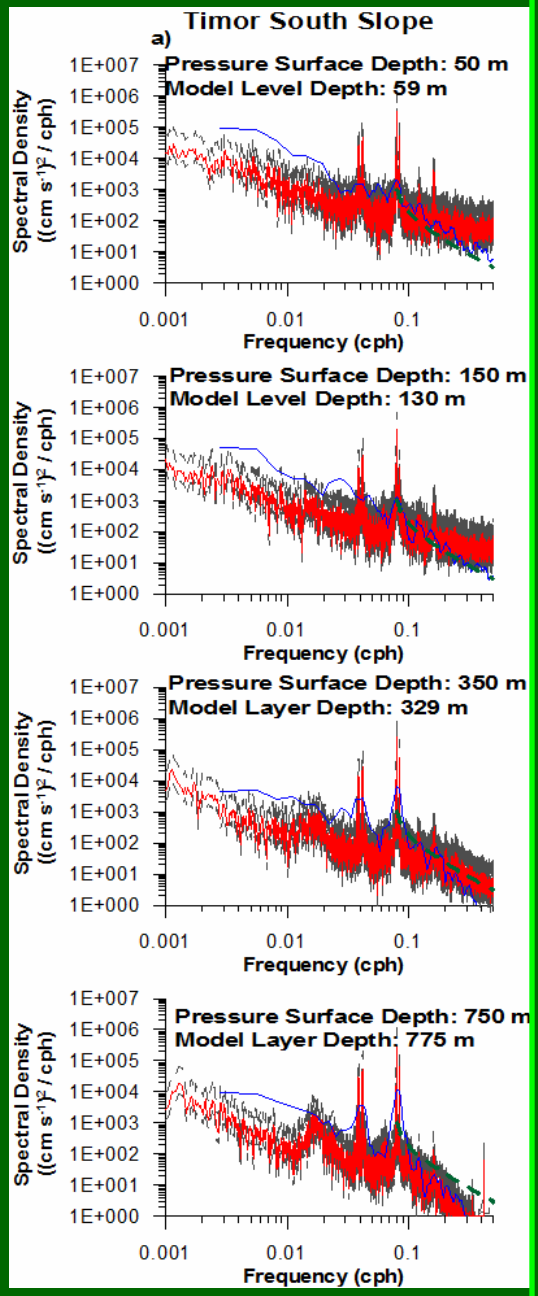


M_2 Internal Tides for Transect across the INSTANT Moorings



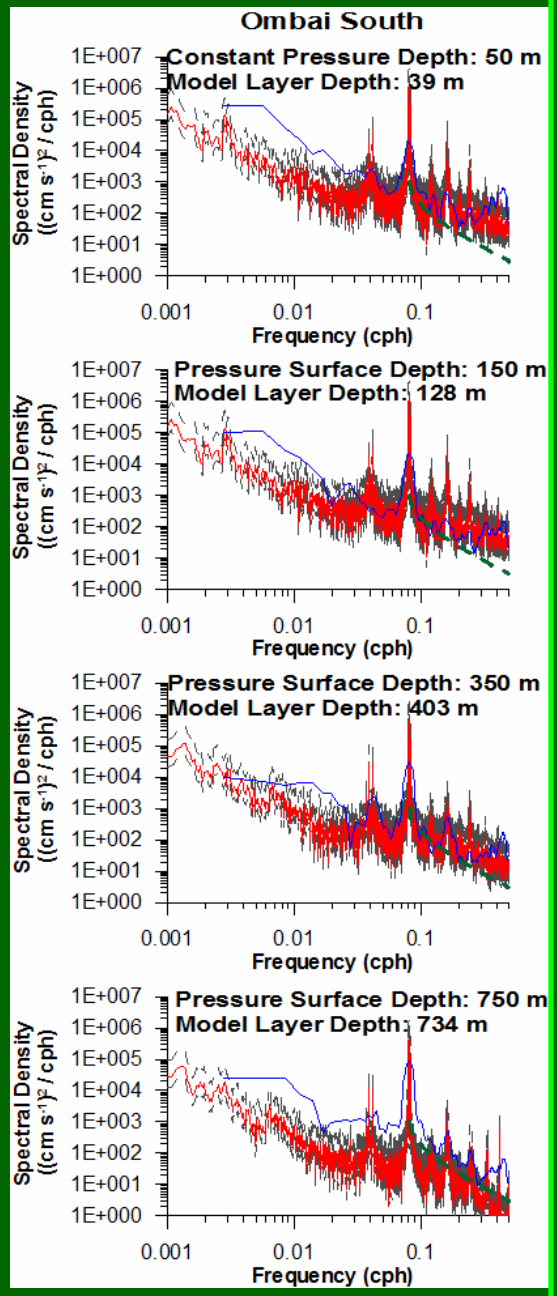
A Region of Inactive/Background Internal Tides

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



A Region of Active Internal Tides

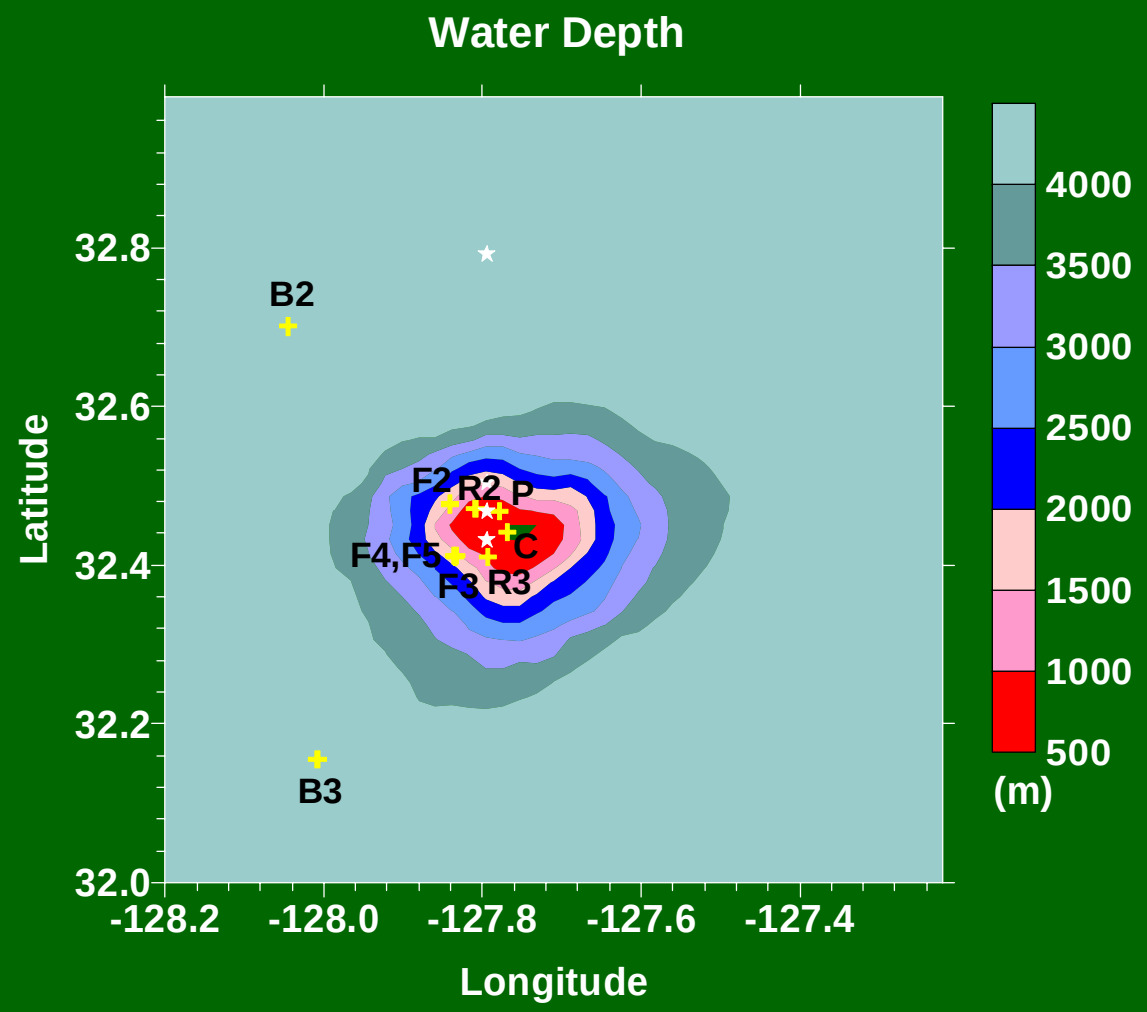
- Harmonics peak up for both the model and the observations (red and black)
- Energy levels above Garrett-Munk (dashed green line at high frequencies
- Differ at high and low frequency ends



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)
  - κ-ω
  - κ-ε
  - κ-κl
  - Generic -old
  - Generic -new

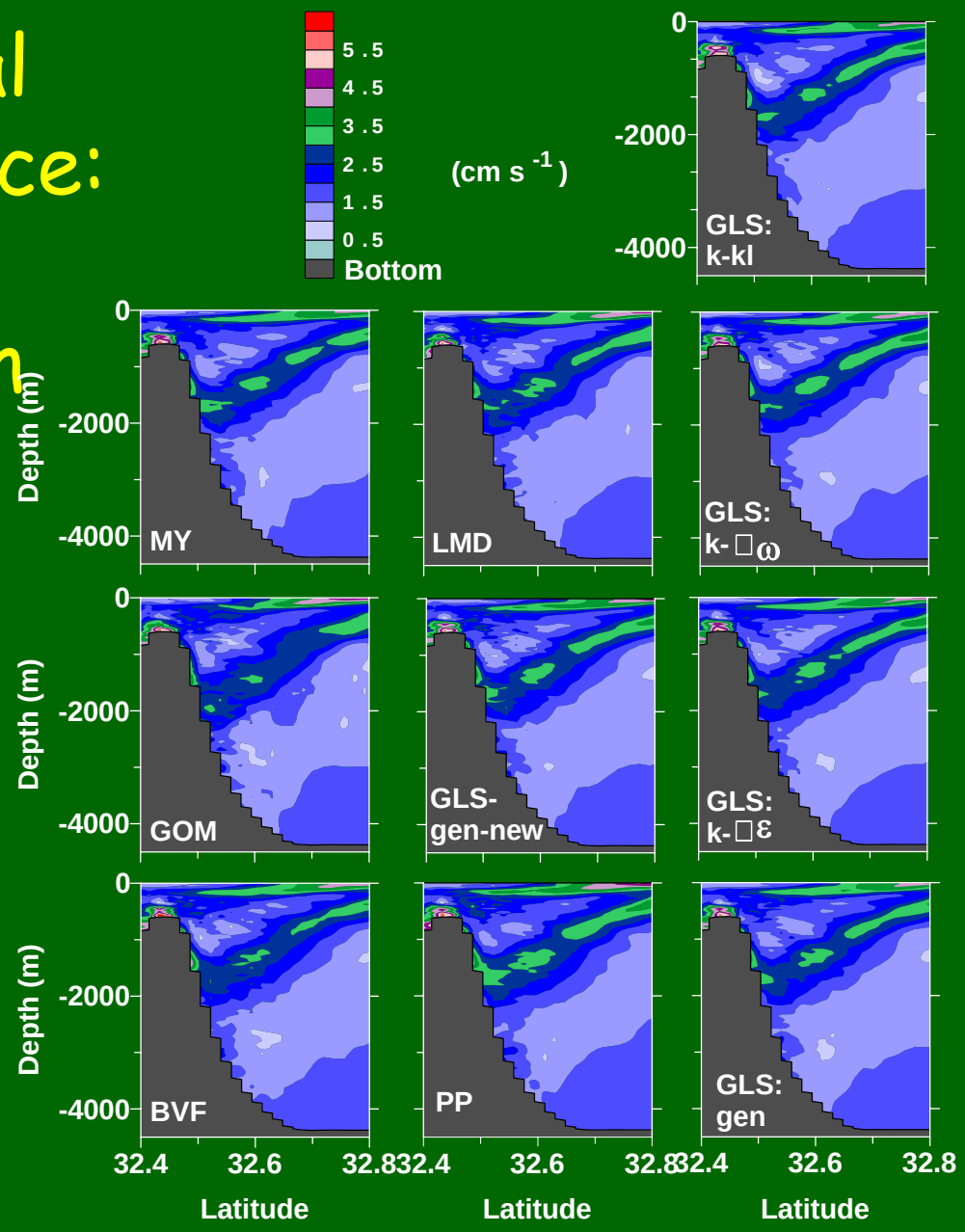
Fieberling Guyot



Evaluated the Performance of these Mixing Parameterizations

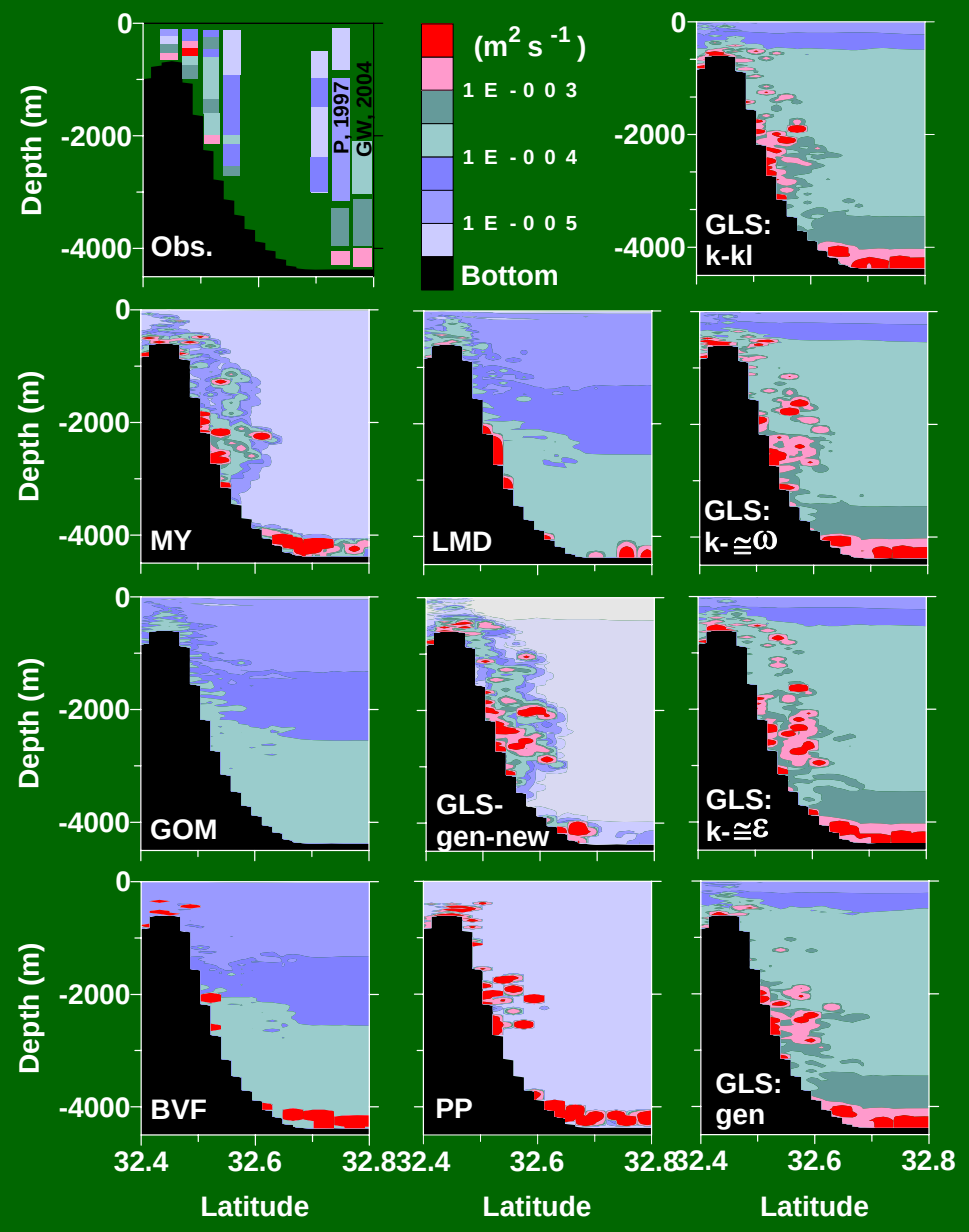
- Internal Tidal model for Fieberling Guyot
- Accessible data set for both velocities and dissipation
- Good agreement for major axes of semidiurnal tidal ellipses between model estimates and observations

Semidiurnal Tidal Velocity Dependence: Vertical Mixing Parameterization



Diffusivity of Temperature: Vertical Mixing Parameterization

Observations (K_ρ) from *Kunze and Toole* (1995; 1997)

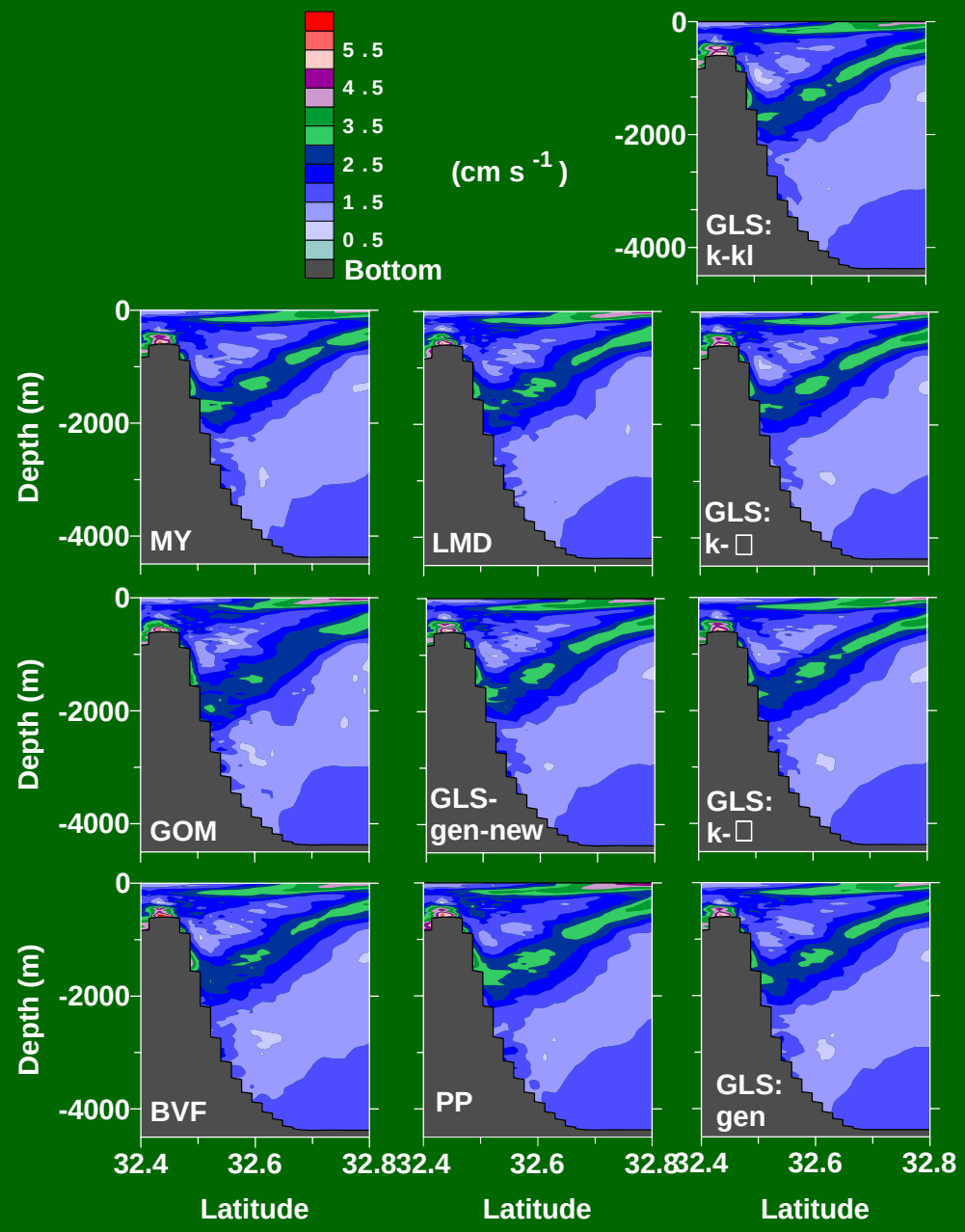


Vertical Diffusivities Averaged over the Region

- MY25* 1.4×10^{-3} m^2 s^{-1}
- GOM 9.0×10^{-4} m^2 s^{-1}
- BVF 1.3×10^{-2} m^2 s^{-1} (way too big)
- LMD* 1.1×10^{-3} m^2 s^{-1}
- LMD-SCCW 1.0×10^{-3} m^2 s^{-1}
- PP 8.0×10^{-5} m^2 s^{-1} (too small)
- GLS- kkl 3.8×10^{-3} m^2 s^{-1}
- GLS- $k\omega$ 3.7×10^{-3} m^2 s^{-1}
- GLS- $k\varepsilon$* 1.9×10^{-3} m^2 s^{-1}
- GLS- gen* 1.8×10^{-3} m^2 s^{-1}
- GLS- gen2* 3.7×10^{-4} m^2 s^{-1} (looks best; good value)

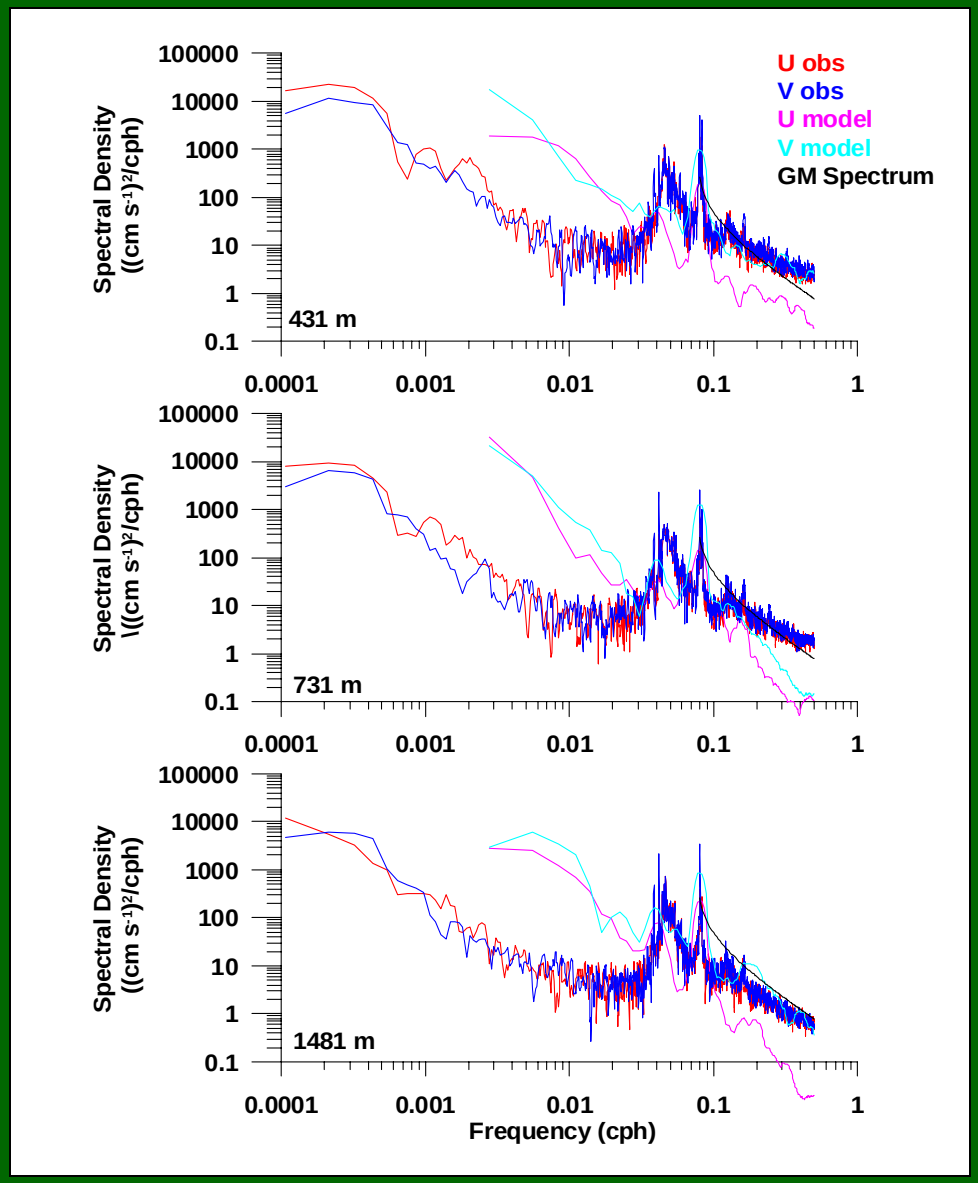
Is there really no difference in the velocities?

- 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

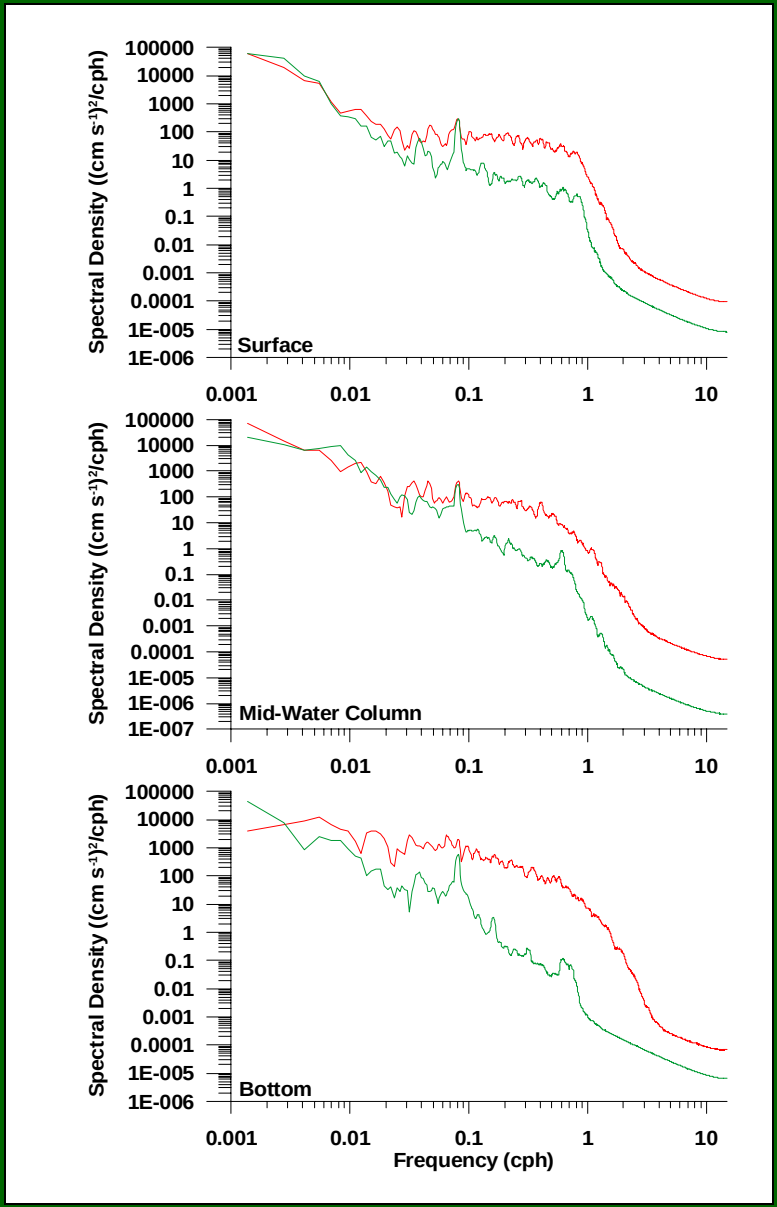
- Why do the spectra follow Garrett-Munk?
- Which one is the best performer?

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

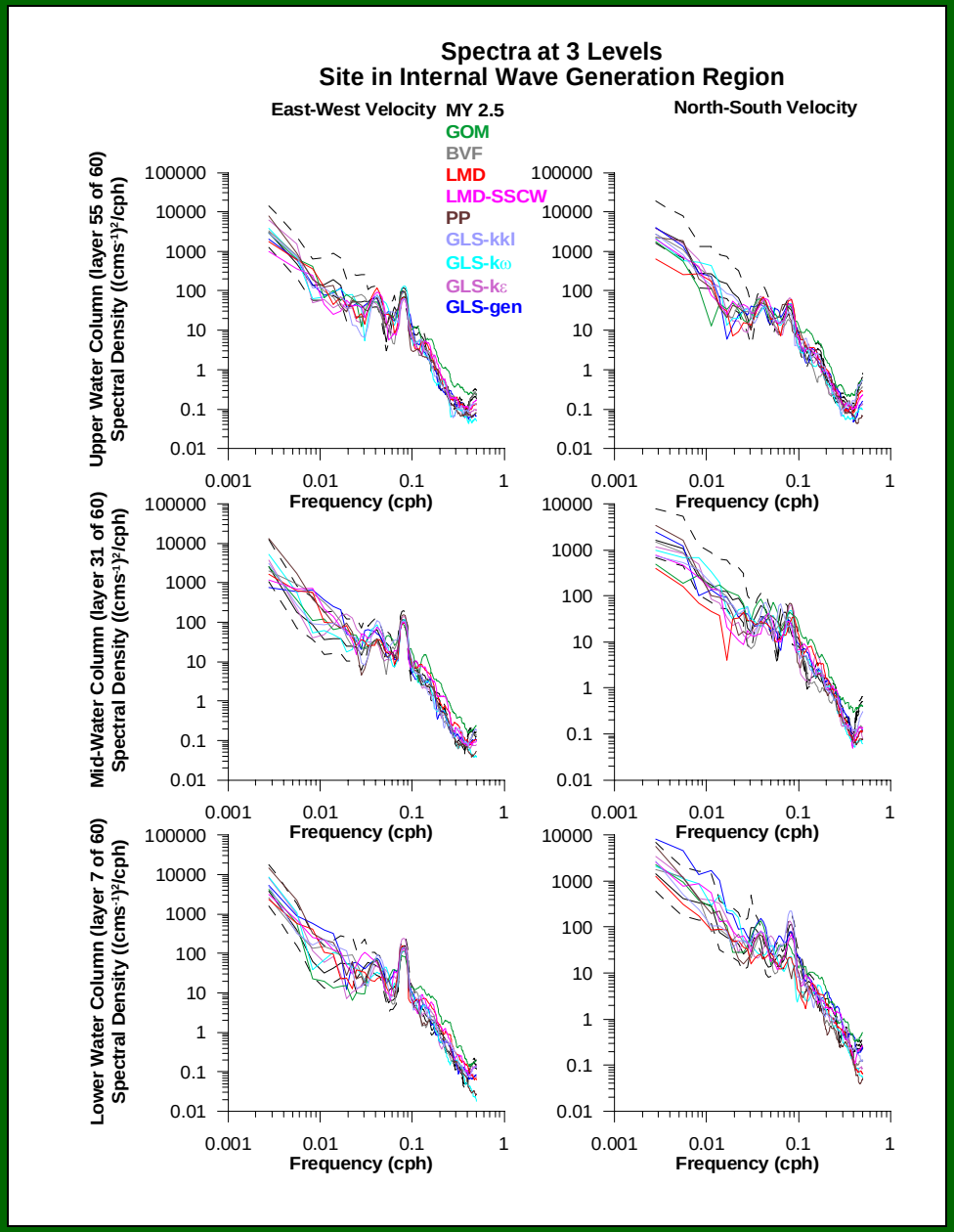
Black – with vertical diffusion

Red – without vertical diffusion



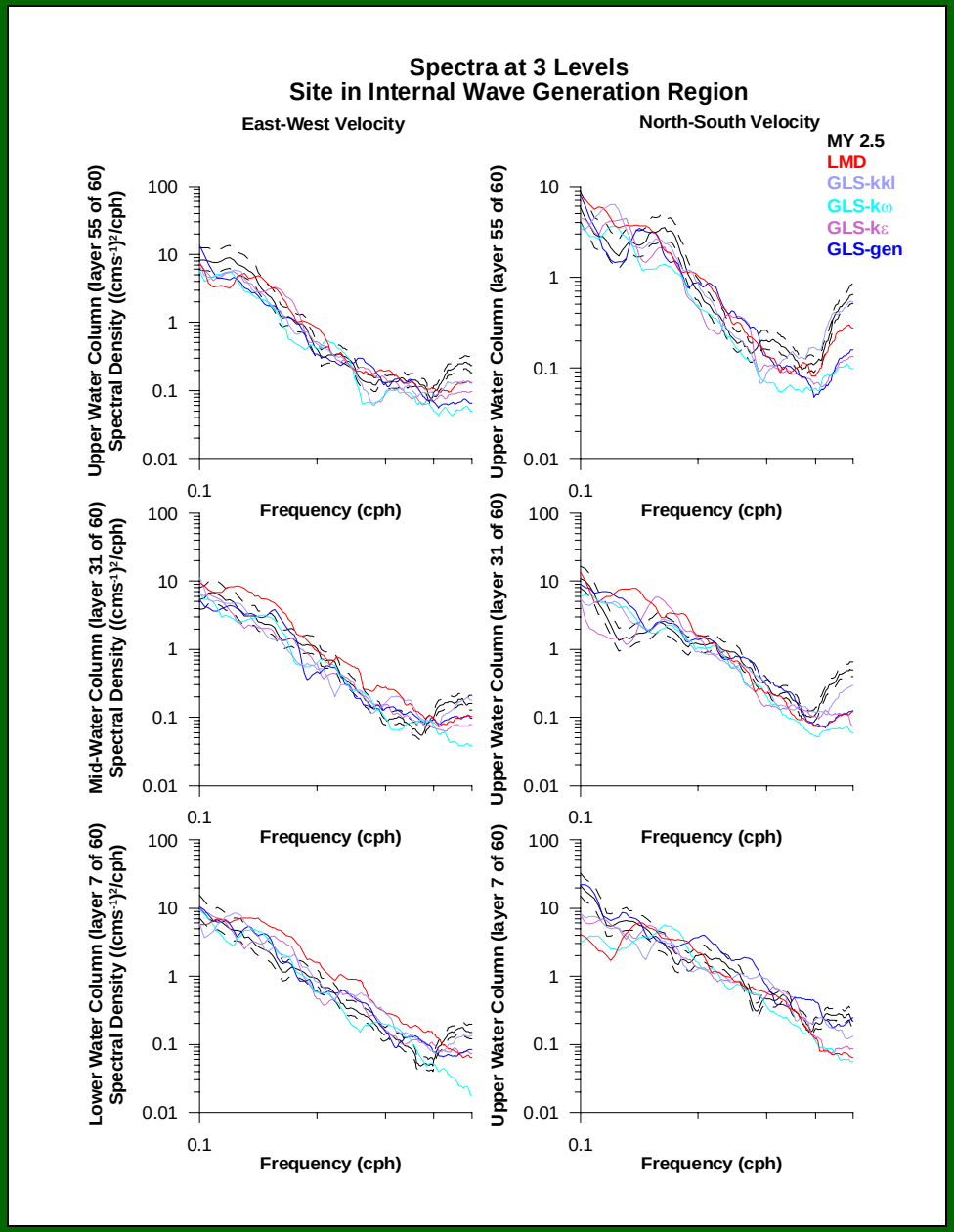
What about Higher Frequencies?

- 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)



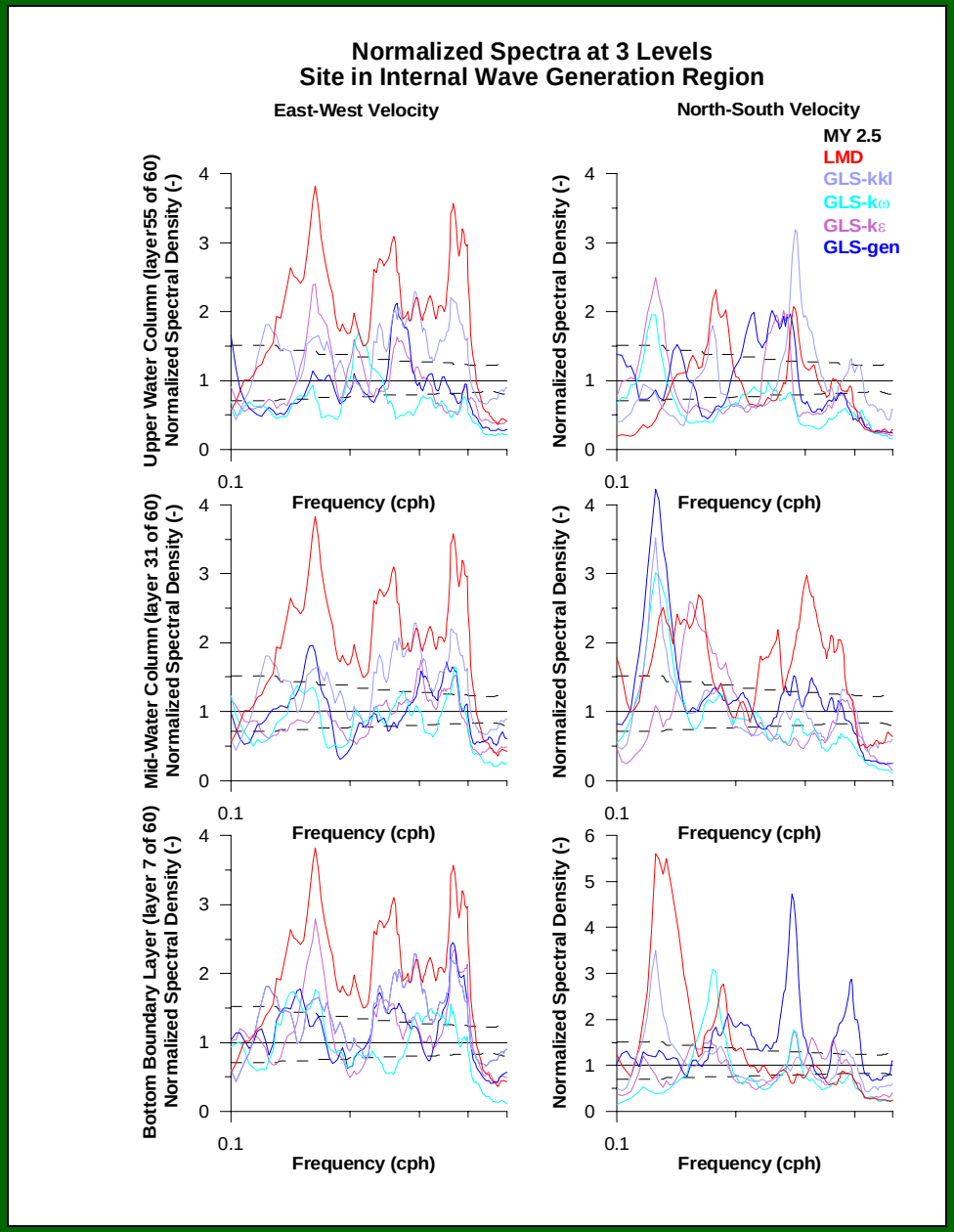
Focusing on Higher Frequencies

- 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-$\kappa\omega$ 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

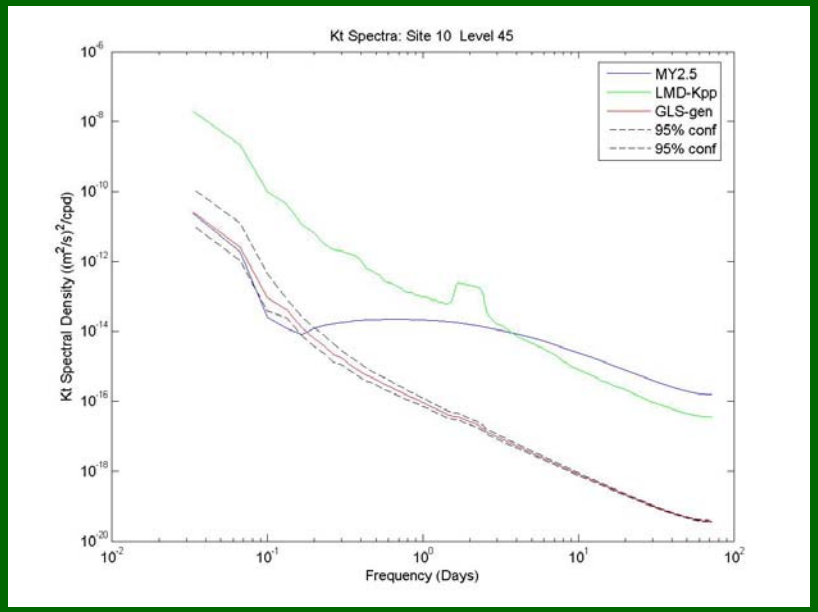
- All 10 vertical mixing schemes generated spectra roughly following G-M
  - Believed to be due to non-linear interactions and the vertical mixing parameterization

- Best performers are:
  - GLS-gen (new)
  - GLS-$\kappa\omega$, 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?