How Realistic is the Internal Tide Energy Decay in a Global Ocean Model?

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Introduction

On this poster we explore how well global HYbrid Coordinate Ocean Model (HYCOM) simulations predict (semidiurnal) internal tides and their decay.

We explore two important factors that govern the internal tide predictability: **model resolution** (8 km vs. 4 km) and **wave drag**.

We validate these simulations with internal-tide sea-surface height amplitudes from altimetry, surface-tide dissipation rates estimated from an altimetry-constrained model, finestructure and microstructure dissipation rates, and modal-conversion rates computed from analytical models.

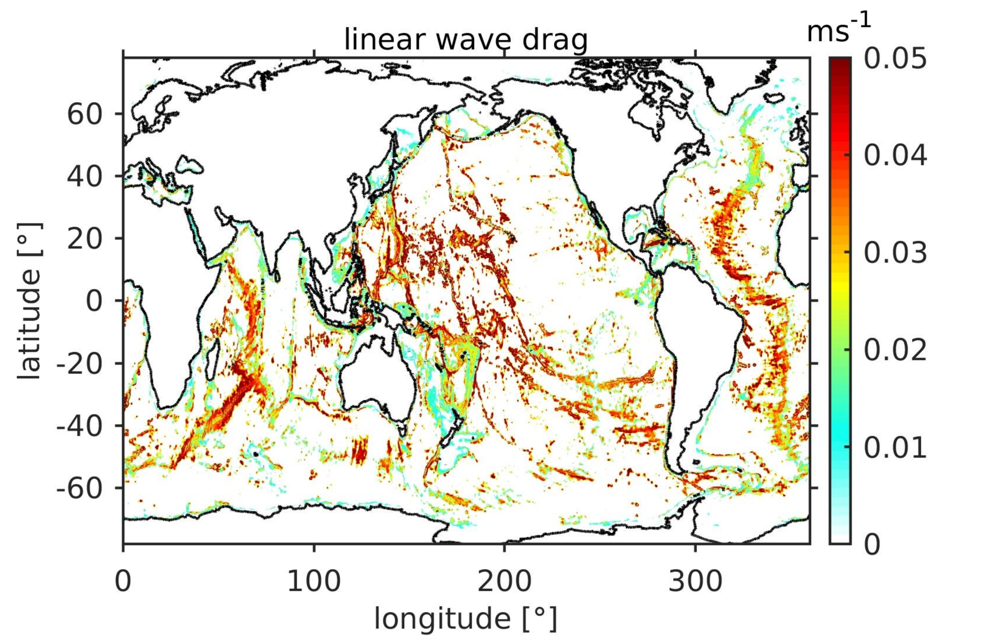
To compare HYCOM to various altimetry data sets, we derive a spatially varying correction factor that accounts for the effect of time series duration on non-stationarity.

We perform tidal **energy balances** and decompose the M_2 internal tides into **vertical modes**.

-1- HYCOM and Wave Drag Tuning

HYCOM is the operational forecast model of the U.S Navy. We perform global forward simulations with realistic tidal and atmospheric forcing and a spatially varying Self Attraction and Loading (SAL) (Ngodock et al, 2016) on a tripolar grid with 41 layers and a horizontal resolution of 8 km (H12) and 4 km (H25).

We apply a linear wave drag $\mathbb{C} = \frac{\pi}{L}\widetilde{H}^2 N_b$ to the tidal flow in the bottom 500 m to account for the unresolved higher modes and to dampen the resolved internal tides.



The tidal sea-surface amplitudes are optimized relative to TPXO8-atlas, by tuning the wave drag with a dragscale. The H12 and H25 simulations obtain optimal M_2 SSH amplitudes for a **dragscale of 0.5** and a **dragscale of 0.3**, respectively (a 40% reduction). The global-mean Root-Mean-Square Error (RMSE) with TPXO for both the 8 and 4 km simulations is about 2.7 cm. **Does a 40% reduction in damping make the internal tides too energetic in H25 as compared to H12?**

-2- The Undecomposed M_2 Energy Balance

For the H12 and H25 simulations we compute time-mean, depth-integrated energy balances for a two-week time series for M_2 surface tides:

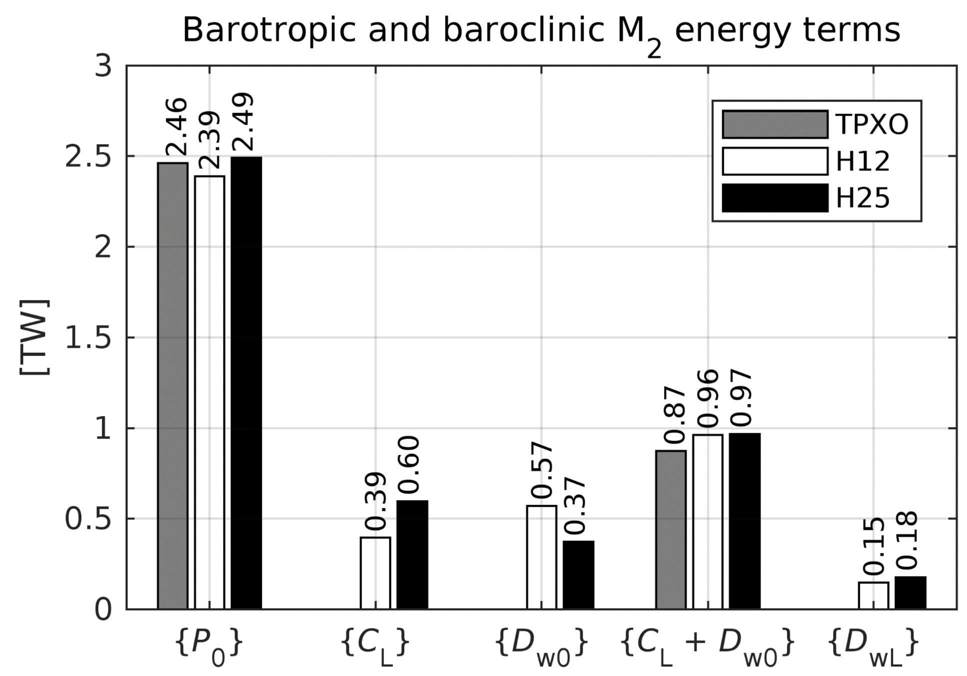
$$P_0 = \nabla\cdot\mathbf{F}_0 + C_L + D_{w0} + D_{b0} + \mathcal{R}_0$$

and internal tides

$$C_L = \nabla\cdot\mathbf{F}_L + D_L$$
$$D_L = D_{wL} + D_{bL} + \mathcal{R}_L$$

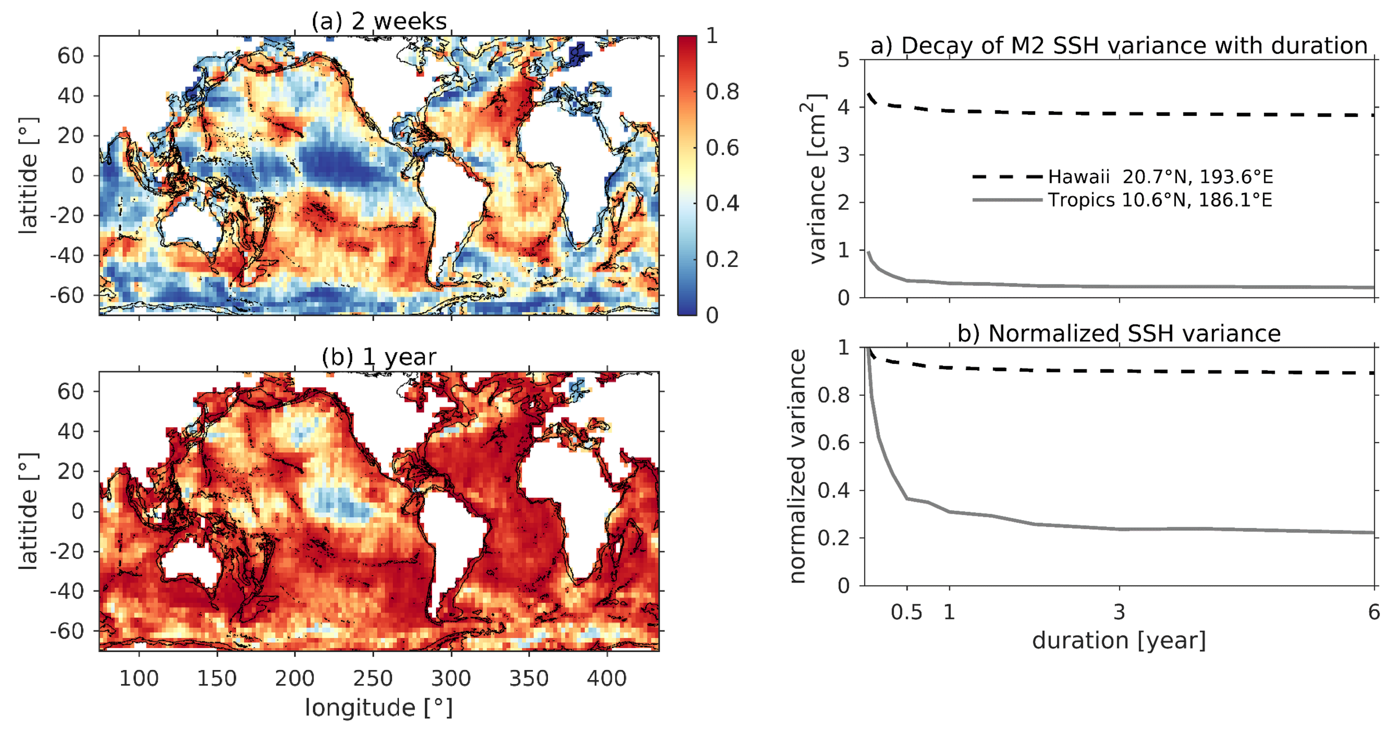
Where P_0 is the energy input by the sun and the moon, $\mathbf{F}$ the flux vector, C_L the barotropic energy conversion to the resolved low modes, D represents the energy loss to the wave drag (w) and bottom drag (b). Subscripts (0) and (L) indicate barotropic and low-baroclinic mode.

H25 generates more internal tide energy (C_L) than H12, while the surface tide energy lost to the wave drag (D_{w0}) has been reduced. Their sum (C_L + D_{w0}) agrees with TPXO8-atlas dissipation rates in both H12 and H25.



-A- Correction for Time Series Duration

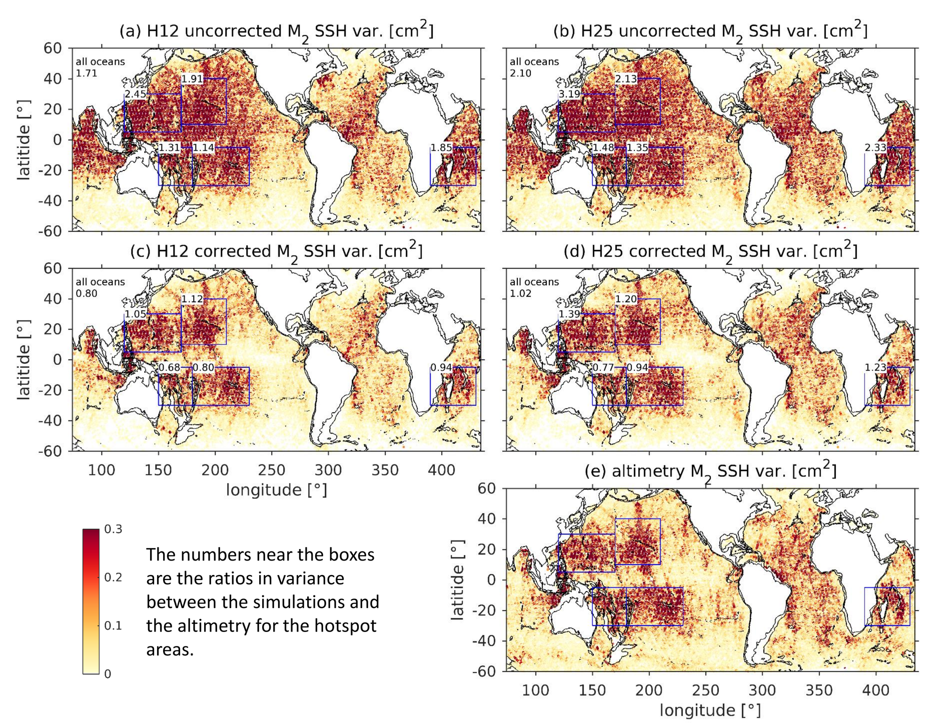
The tidal amplitude extracted from a time series with a least-squares harmonic analysis is inversely proportional to the duration of the time-series. To compare time series with different durations we compute a correction factor from a 6-year long HYCOM time series of SSH. In most places the variance equilibrates for time series longer than 6 years (bottom right figure). The bottom left figure shows the correction factors for a 2-week and 1-year long time series. To compare with altimetry variance, this correction factor is multiplied with the HYCOM variance.



-3- M_2 SSH Validation

The M_2 steric sea-surface height of H12 and H25 is validated with SSH variance computed from a 17-year long altimetry record.

After we correct for the effect of the time series duration on stationary variance (**Panel A**), the H12 and H25 simulations are in better agreement with the altimetry (to within 2% for H25).



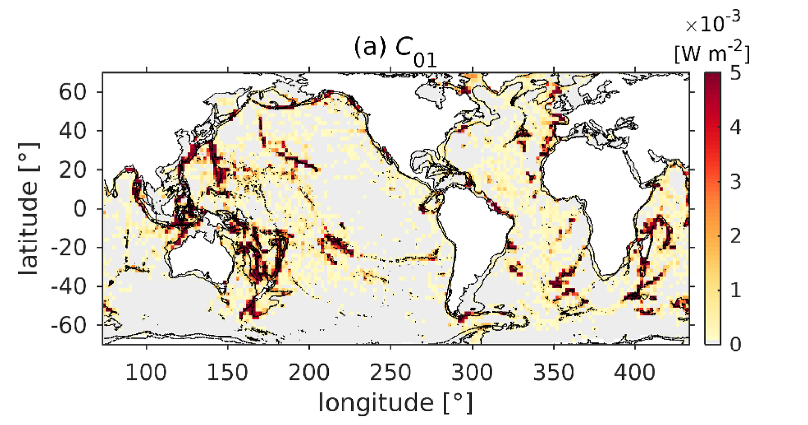
-4- Modal Energy Conversion

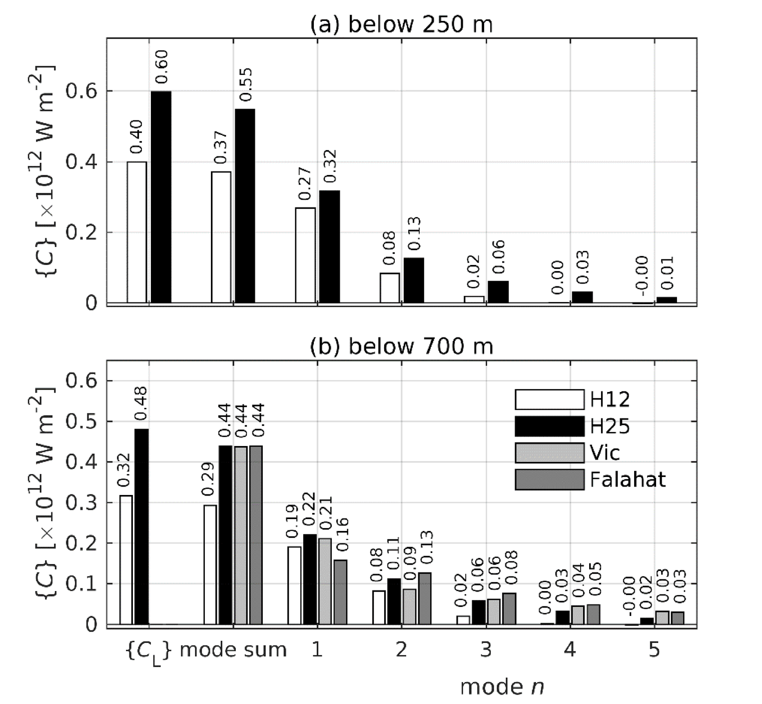
The simulations are decomposed into vertical modes. We compute the time-mean and depth-integrated M_2 modal energy balance according to Kelly et al (2012):

$$\underbrace{\sum_{m=0}^{5} C_{mn}}_{\text{Conversion}} = \frac{\rho_c H}{4}\left[\underbrace{|\hat{\mathbf{u}}_n|^2}_{KE} + \underbrace{\left(1-\frac{f^2}{\omega^2}\right)\frac{|\hat{p}_n|^2}{(\rho_c c_n)^2}}_{APE}\right]_t + \underbrace{\frac{1}{2}\nabla\cdot(H\hat{\mathbf{u}}_n^*\hat{p}_n)}_{\text{Flux Div.}} + \underbrace{D_n}_{\text{Dissipation}}$$

We find that in H12 only modes 1 and 2 are generated, while in H25 modes 1-5 are generated. The horizontal model resolution is the limiting factor. Compared to H12, the mode-1 conversion in H25 has increased by 19%.

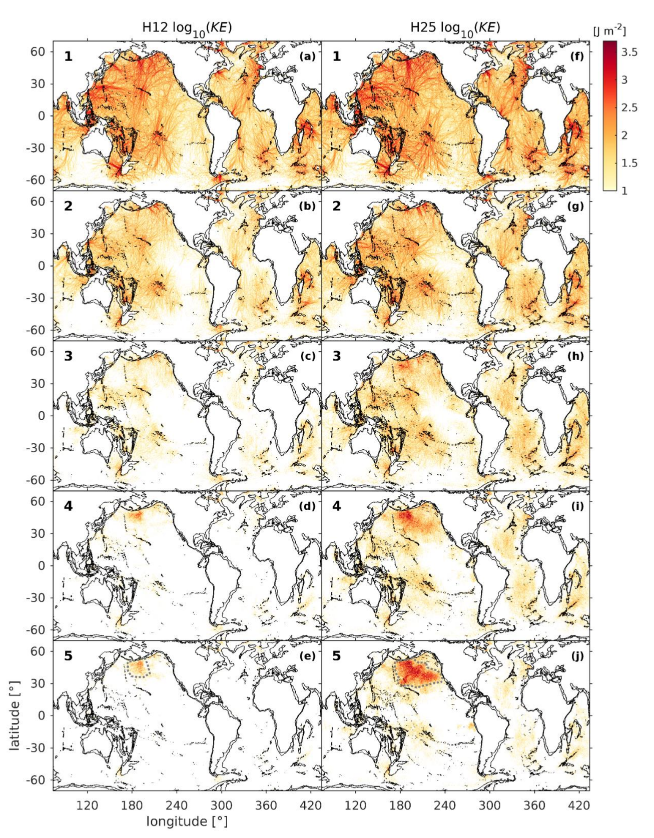
The barotropic to baroclinic conversion rates to modes 1-5 agree well with analytical models of the surface tide energy loss in deep water by Vic et al (2019) and Falahat et al (2014).





-5- Internal Tide Energy

While the differences in modal energy flux and energy density are small for mode 1, the differences are substantially larger for the higher modes for the H12 and H25 simulations. Compared to H12, the mode-1 energy in H25 has increased by 34%.

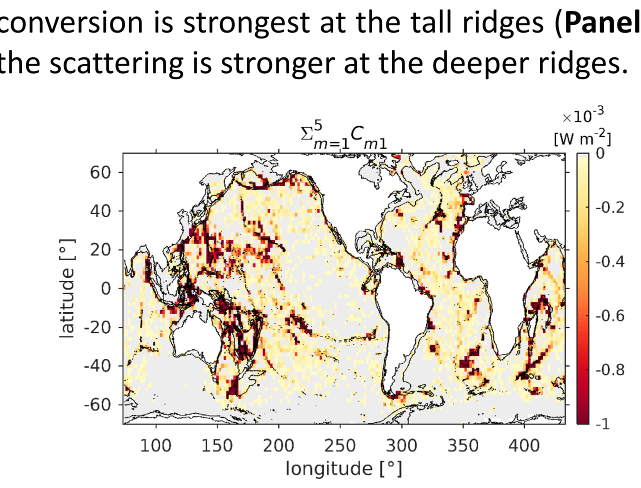


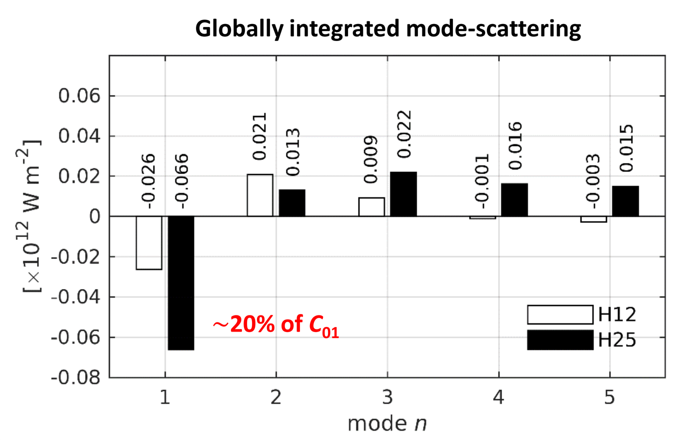
-6- Topographic Scattering

As the low-mode internal tide interacts with underwater topography it scatters to higher modes. The mode to mode scattering term is computed as

$$C_{mn} = \int_{-H}^{0} \mathbf{u}_m^* \cdot \nabla p_n - \mathbf{u}_n^* \cdot \nabla p_m \,\mathrm{d}z$$

Energy is scattered from mode 1 to the higher modes and the scattering is twice as strong in H25 than in H12. While the barotropic to baroclinic conversion is strongest at the tall ridges (**Panel 4**), the scattering is stronger at the deeper ridges.

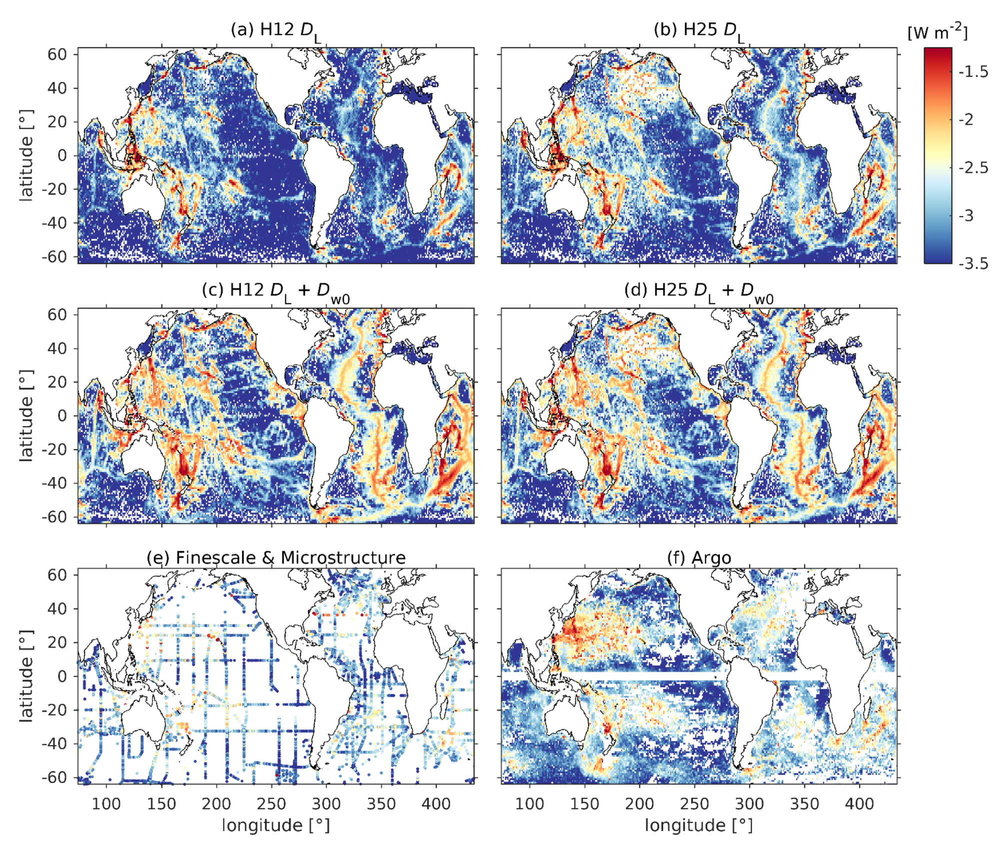


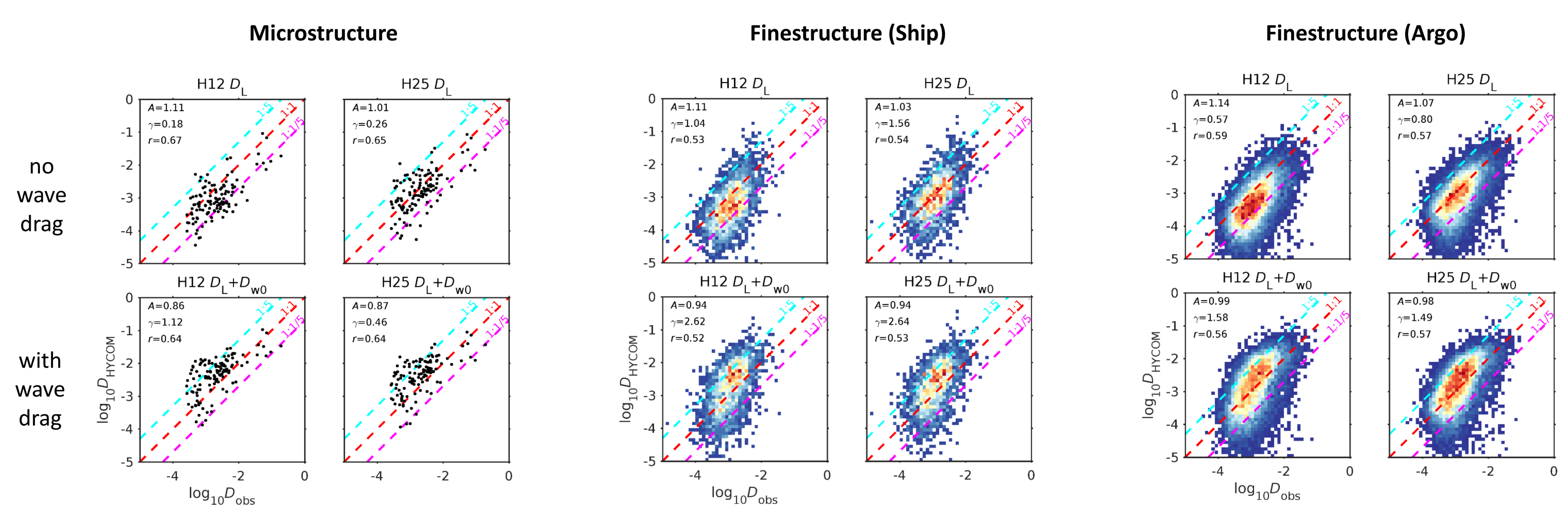


-7- Internal Tide Dissipation

The patterns of resolved internal tide dissipation (D_L) and the resolved and parameterized dissipation (D_L + D_{w0}) for the diurnal and semidiurnal bands agree reasonably well with microstructure and finestructure observations (Water-house et al, 2014, Kunze, 2017, Whalen et al, 2018). All fields are averaged to 1°. Note the high-mode dissipation over the Mid Atlantic Ridge in H25, which is lacking in H12.

The sum of the resolved and para-meterized dissipation (D_L + D_{w0}) is more than twice as large than the finestructure observations in H12 and H25, but on average smaller than the microstructure observations (compare γ). The correlation r is also best for microstructure.





Conclusions

- In the higher resolution 4-km simulation (H25), the reduction in surface tide energy loss to the wave drag is offset by an increase in conversion to resolved baroclinic modes in H25 (**Panels 2 & 4**).
- H12 (H25) resolves 2 (5) modes (**Panels 4-5**).
- In our simulations, horizontal and not vertical resolution is the limiting factor in resolving vertical modes (**Panel 5**).
- The increase in mode-1 energy in H25 is not proportional to the reduction in baroclinic damping by the wave drag (it is less) because scattering and wave-wave interactions are better resolved in H25 (**Panel 6**).
- H25 agrees better with observations and analytical models than H12 ($\pm$10%; **Panels 2-4**), but the discrepancy is larger with dissipation observations, in particular for finestructure (compare γ; **Panel 7**).
- The wave drag is not designed to dampen internal tides; we are somewhat lucky in this model set-up.
- A more extensive validation with dissipation observations is underway.