

Tidal mixing over rough topography

Maxim Nikurashin and Sonya Legg

- Motivation
- Experiment setup
- Simulations vs. observations
- Energy dissipation mechanism
- Parameter sensitivity

Observation of enhanced mixing

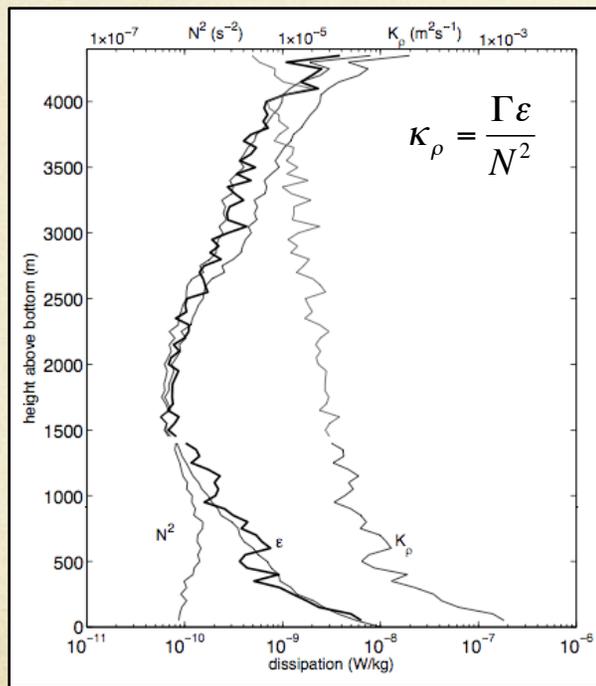


Fig. Profiles of energy dissipation rate, diapycnal diffusivity, and stratification (Polzin, 2009)

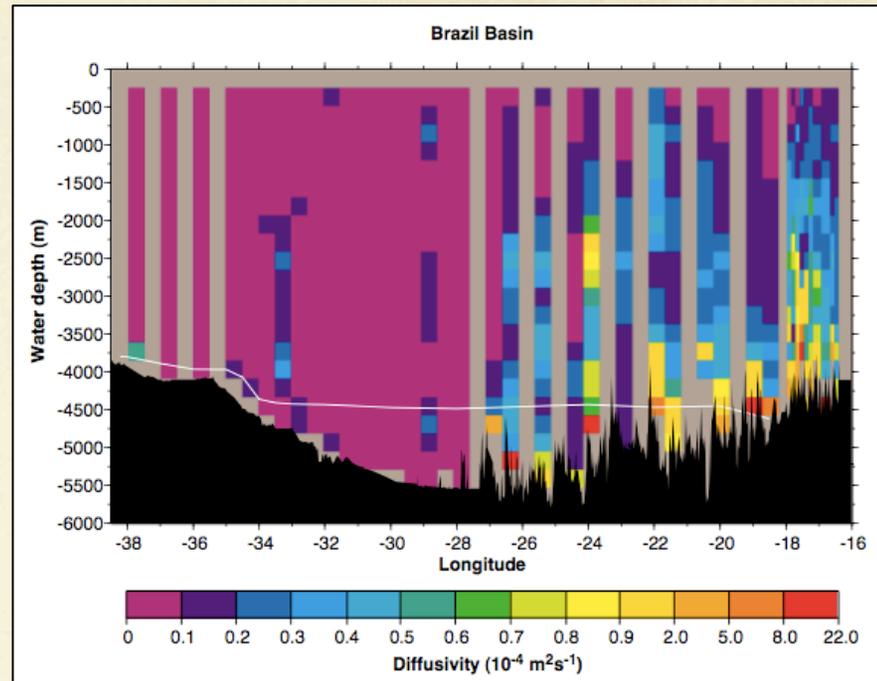


Fig. Diapycnal diffusivity in the Brazil Basin (Polzin et al. 1997)

- enhanced above rough topography
- enhanced in the bottom kilometer
- upward energy propagation

Mixing is sustained by breaking internal waves generated by abyssal flows over rough topography

Tidal mixing parameterization

- Energetically consistent tidal mixing parameterization (Simmons et al., 2003):

Diapycnal diffusivity:

$$\kappa = \kappa_0 + \Gamma \frac{\varepsilon}{N^2}$$

background diffusivity, $10^{-5} \text{ m}^2/\text{s}$ mixing efficiency, 0.2 stratification

Energy dissipation rate:

$$\varepsilon = E(x, y, t) \cdot q \cdot F(z)$$

energy conversion fraction of local dissipation, 1/3 vertical structure

Bottom energy conversion:

$$E(x, y, t) = \frac{1}{2} \rho_0 (h^2 k) N_b U_0^2$$

topographic characteristics bottom stratification tidal amplitude

Vertical structure:

$$F(z) = \frac{e^{(z-H)/\xi}}{\xi(1 - e^{-H/\xi})}$$

vertical decay scale, 500m

— physically based
— *ad hoc*

Questions/problems:

- How much of the observed mixing is due to radiation and dissipation of internal tides?
- What is the mechanism transferring energy from internal tides to the dissipation scales?

- Energy conversion at the *super-critical* topography
- Fraction of energy dissipating locally
- Vertical structure and decay scale

Experiment setup: bottom topography

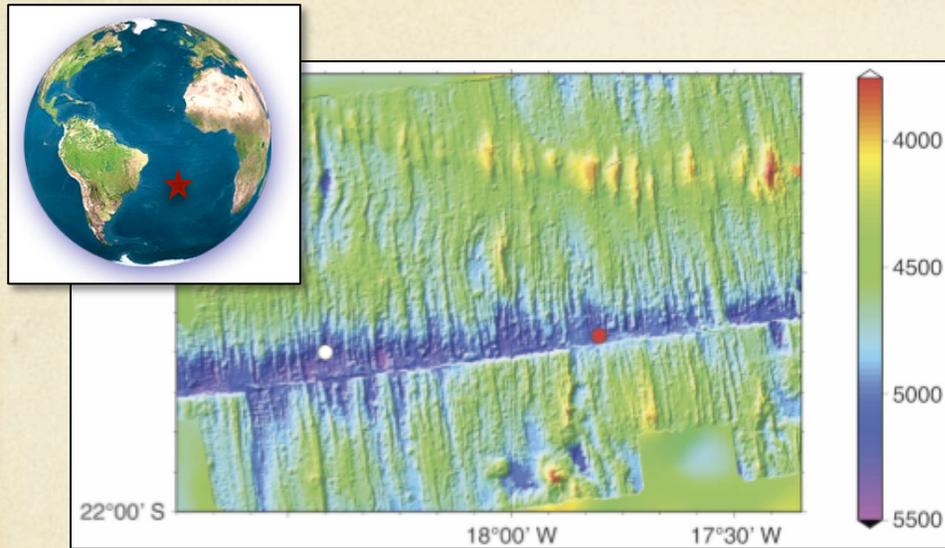


Fig. Multibeam topography of the BBTRE region.

- ❑ There are two types of topographic features: *canyons* (10-100km) and *abyssal hills* (1-10km).
- ❑ Local mixing has been suggested to be sustained by internal waves radiated from *abyssal hills*.
- ❑ *Abyssal hills* are elongated in the direction perpendicular to canyons with an aspect ratio 5: i.e. nearly one-dimensional.



Topography used in simulations is synthetically generated with the same spectral characteristics as *abyssal hills* in the MAR of the Brazil Basin.

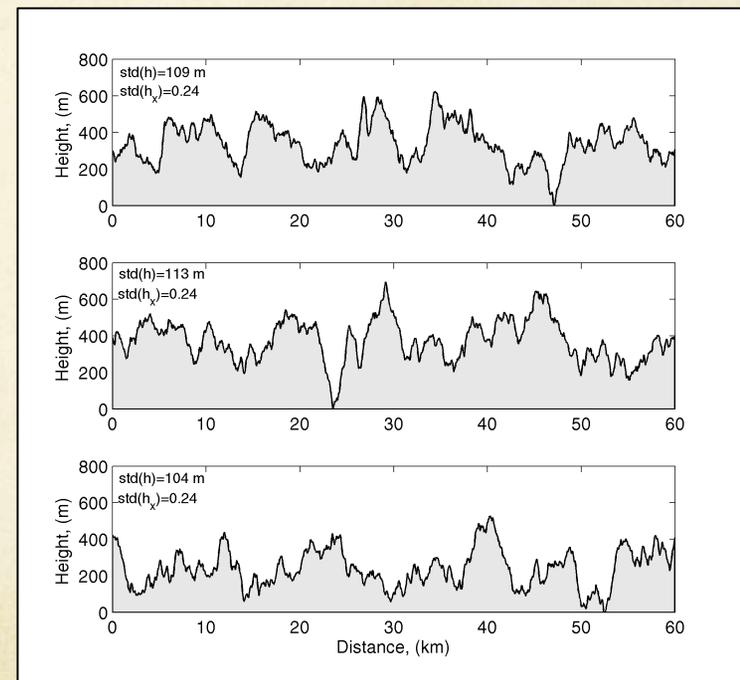
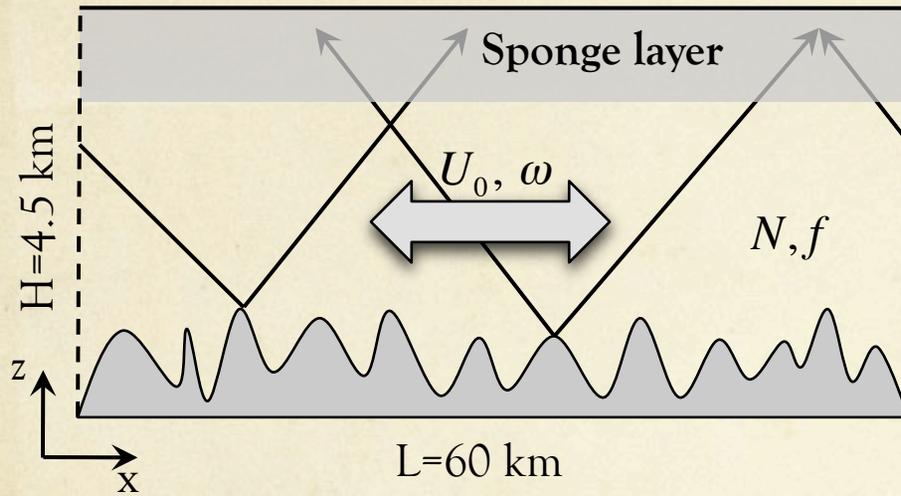


Fig. Realizations of abyssal hill topography used in simulations.

Experiment setup



- MITgcm, nonhydrostatic
- 2-D periodic domain
- Sponge layer at the upper boundary
- Barotropic M_2 tide: $U(t) = U_0 \cos(\omega t)$

- Resolution: $dx=30$ m, $dz=10$ m
- Viscosity $10^{-3} \text{ m}^2\text{s}^{-1}$, diffusivity $10^{-4} \text{ m}^2\text{s}^{-1}$
- Experiments are run for 20 days to a statistically steady state

Brazil Basin parameters:

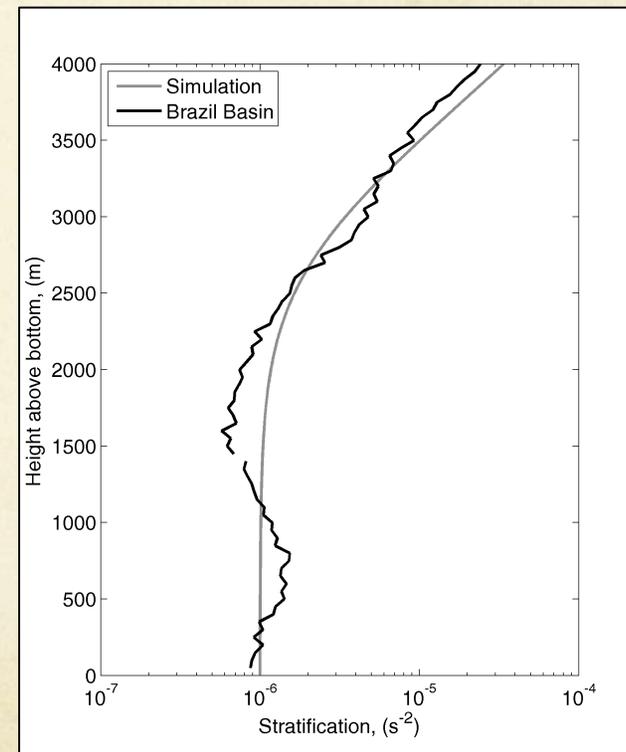
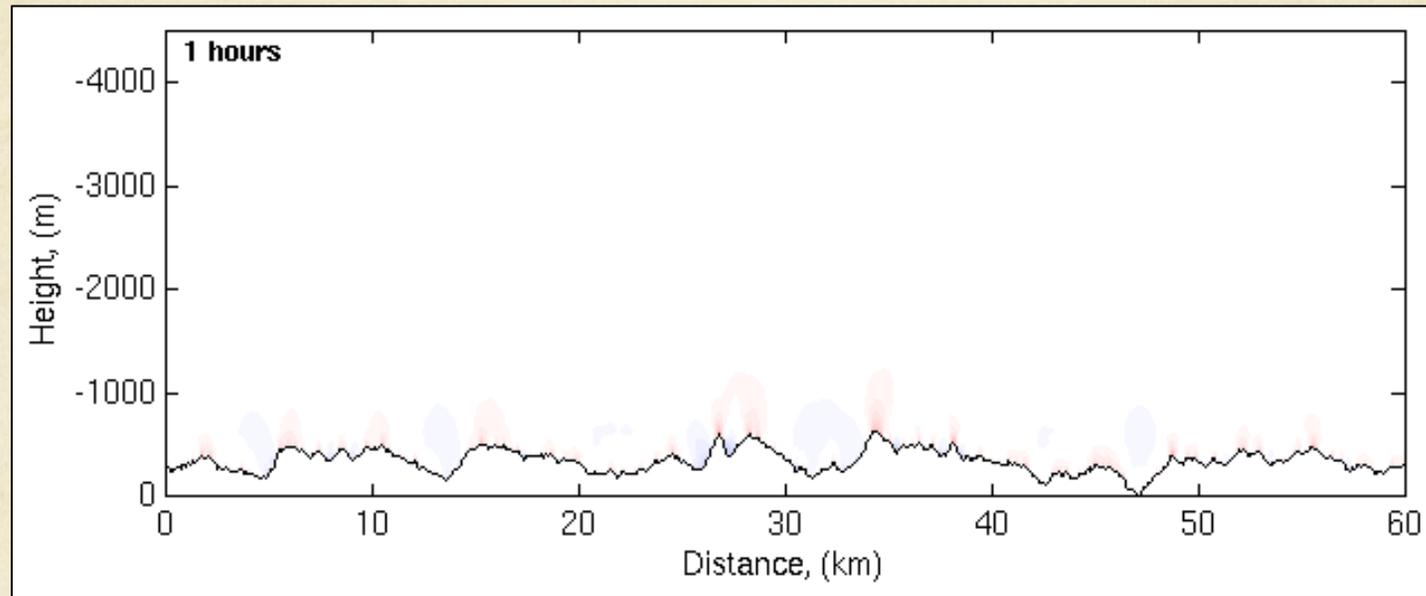
$$U_0 = 2.5 \text{ cm/s}$$
$$\omega_0 = 1.4 \cdot 10^{-4} \text{ s}^{-1}$$
$$f = 0.53 \cdot 10^{-4} \text{ s}^{-1}$$
$$N = 10^{-3} \text{ s}^{-1}$$


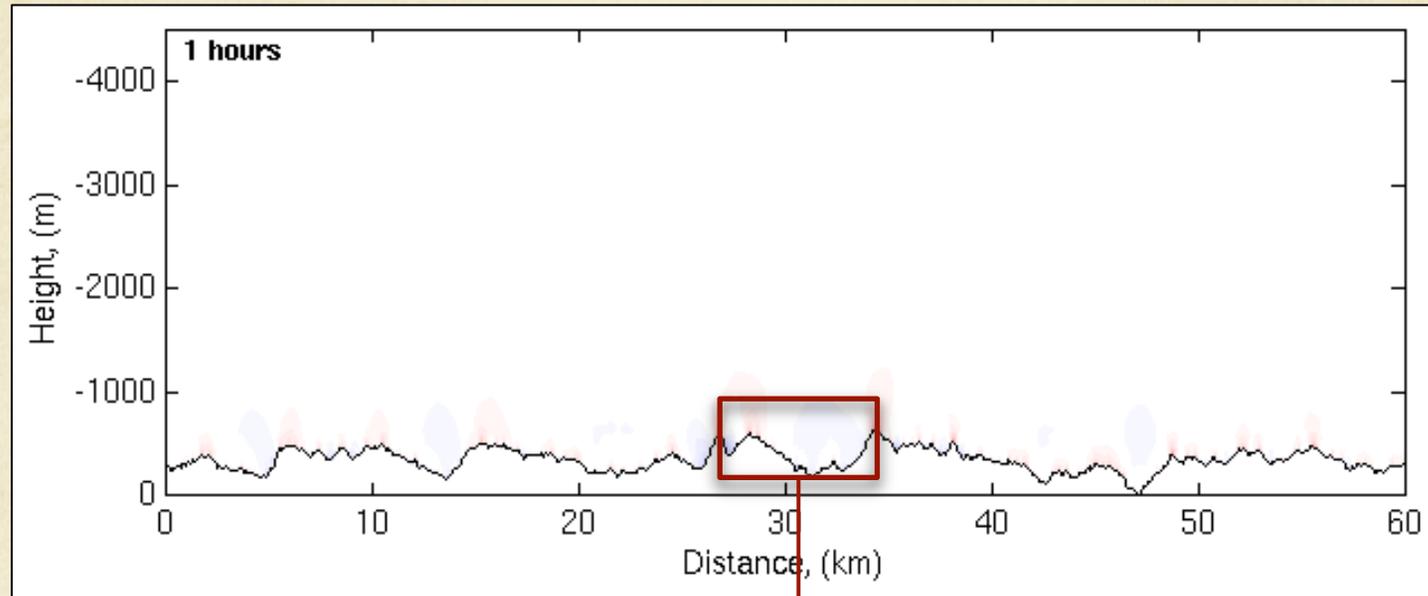
Fig. Stratification used in simulations.

Animations



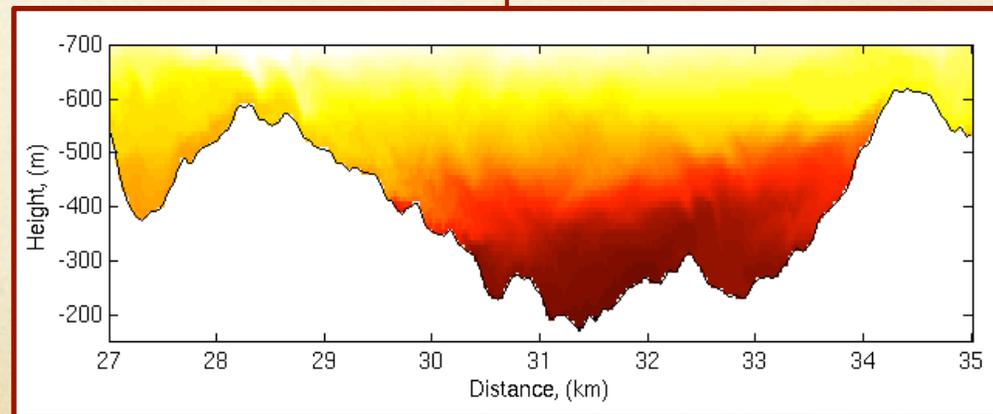
$$u(x,z,t) = U_0(t) + u'(x,z,t)$$

Animations



$$u(x,z,t) = U_0(t) + u'(x,z,t)$$

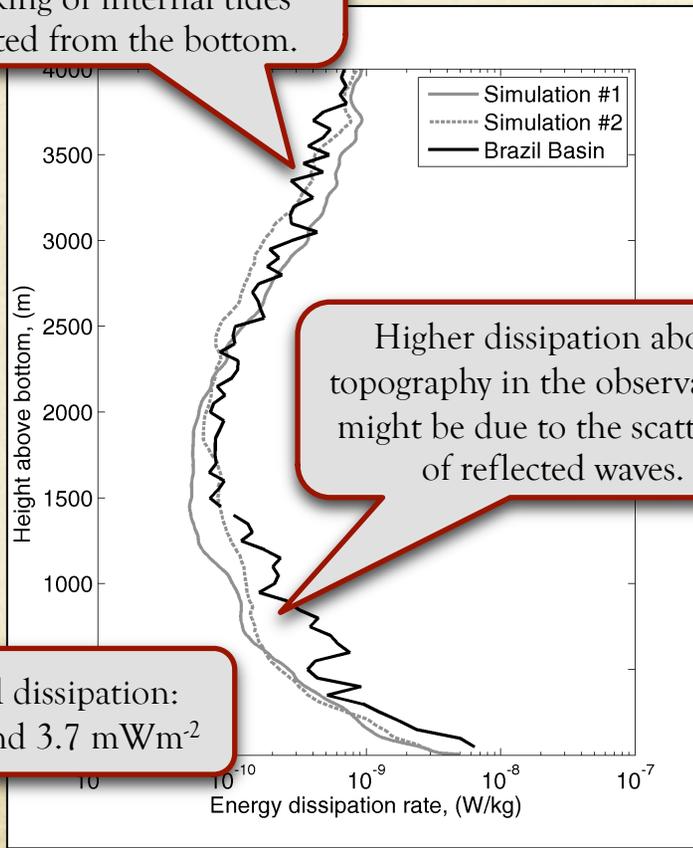
Density



Simulations vs. Observations

Energy dissipation

Enhanced dissipation in the thermocline is sustained by breaking of internal tides radiated from the bottom.



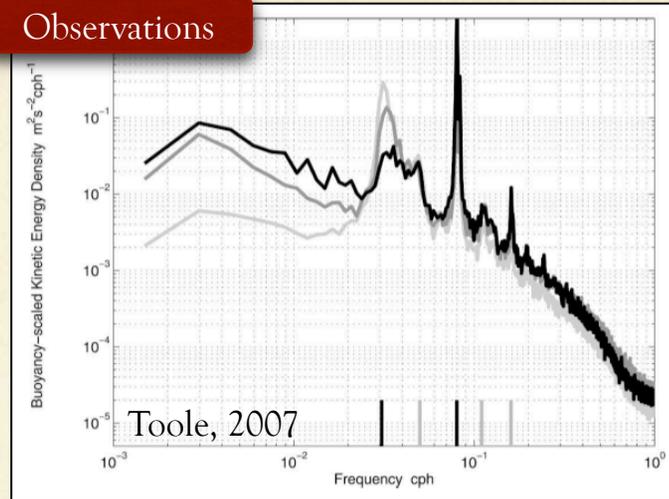
Higher dissipation above topography in the observations might be due to the scattering of reflected waves.

Total dissipation:
3.2 and 3.7 mWm^{-2}

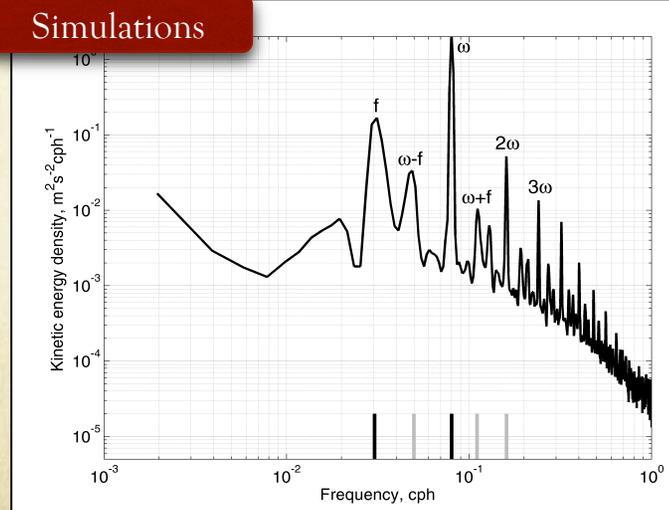
Polzin, 2009

Frequency spectra

Observations

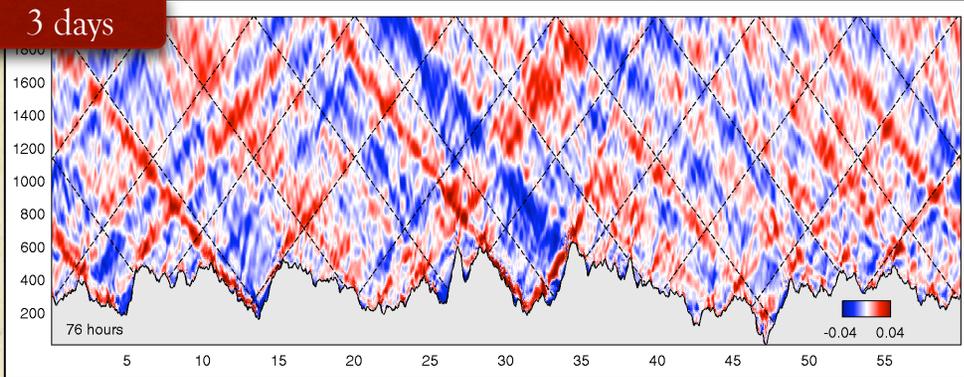


Simulations

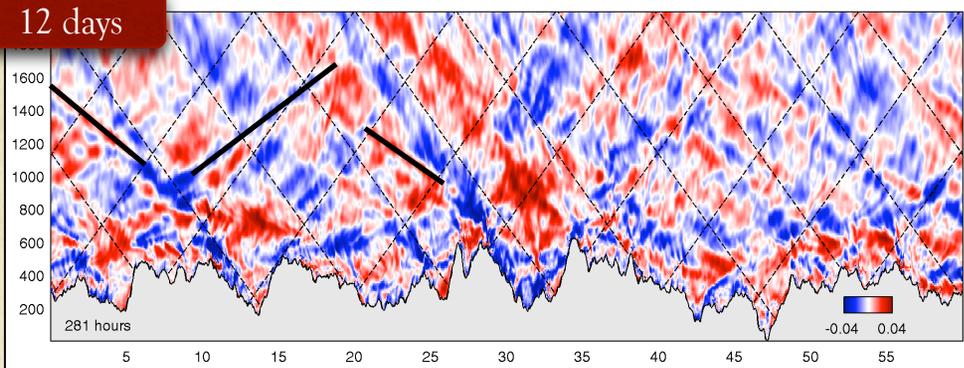


Energy dissipation mechanism: PSI

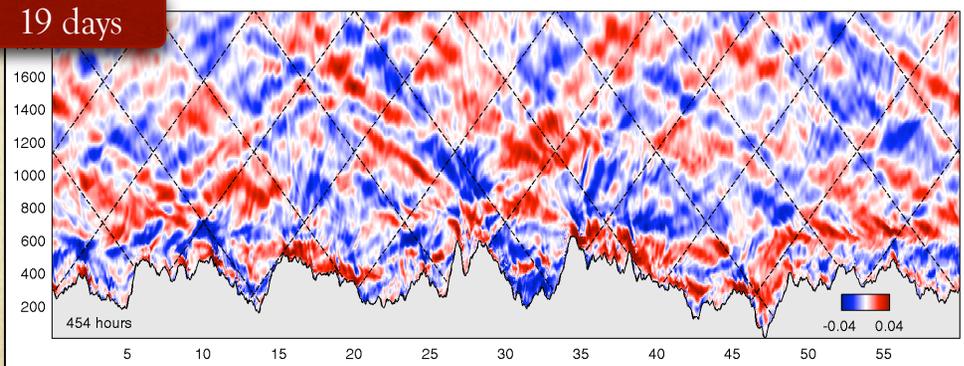
3 days



12 days



19 days



PSI - Parametric Subharmonic Instability

A class of nonlinear wave-wave interactions transferring energy to high vertical wavenumber waves at half the frequency.

Internal wave slope:

$$s = \frac{k}{m} = \sqrt{\frac{\omega^2 - f^2}{N^2 - \omega^2}} \approx \frac{\omega}{N}$$

□ Barotropic tide with frequency ω_0 radiates internal tides at frequencies

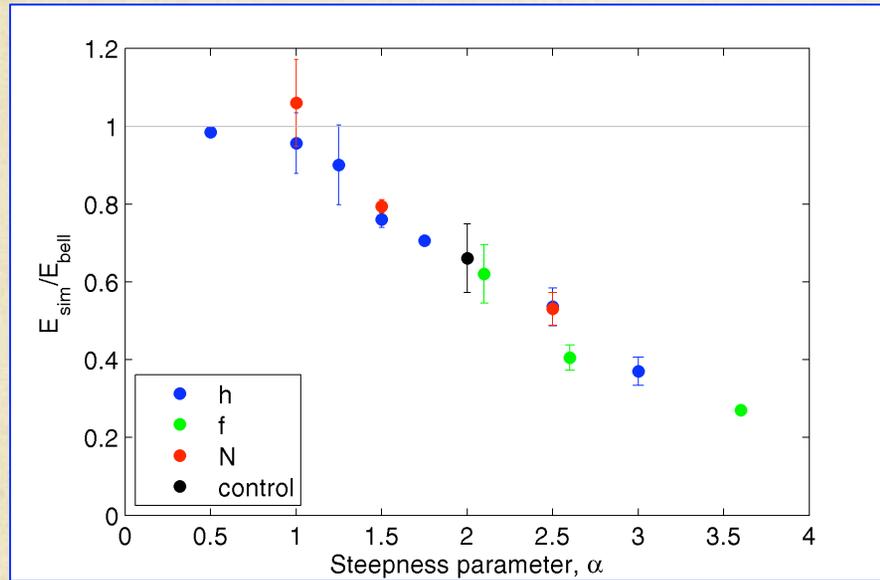
$$\omega_0, 2\omega_0, 3\omega_0, \dots$$

having slopes ω_0/N and steeper.

□ Waves with slopes smaller than ω_0/N are produced by nonlinear wave-wave interactions consistent with the PSI.

□ Through the PSI energy is transferred to the near-inertial waves with a strong vertical shear and dissipated.

Parameter sensitivity: energy conversion



Energy dissipation rate:

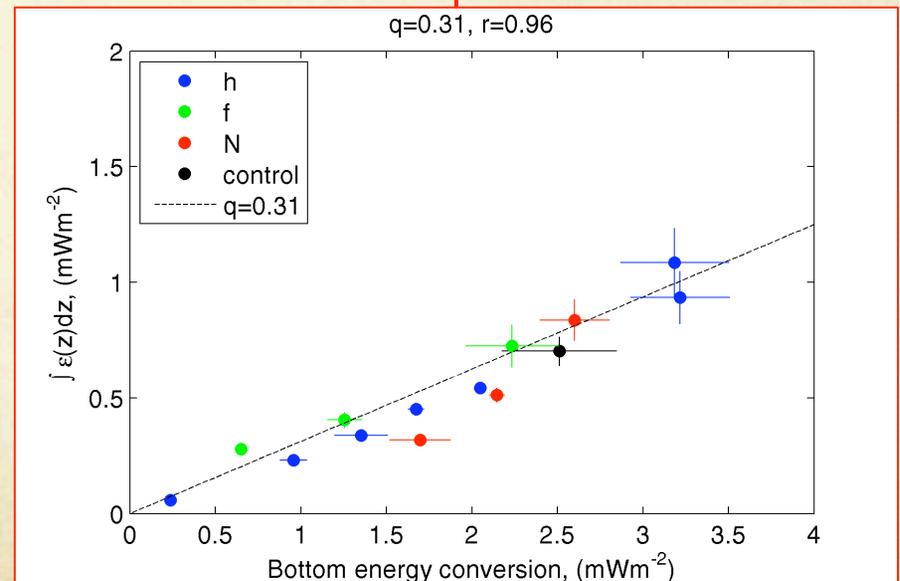
$$\varepsilon = E(x, y, t) \cdot q \cdot F(z)$$

energy conversion (points to $E(x, y, t)$)
 fraction of local dissipation, 1/3 (points to q)
 vertical structure (points to $F(z)$)

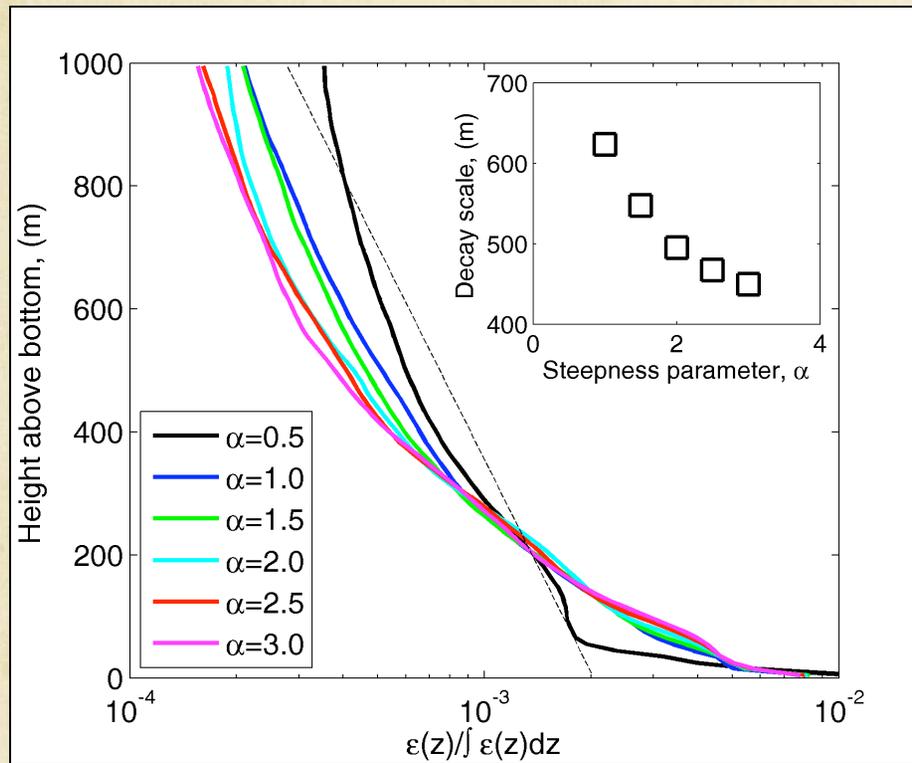
Steepness parameter:

$$\alpha = \frac{\text{wave slope}}{\text{topography slope}}$$

- ❑ Linear theory overestimates energy conversion for super-critical topography
- ❑ A fraction of energy dissipating locally in the bottom 1-2km is 30%



Parameter sensitivity: vertical structure



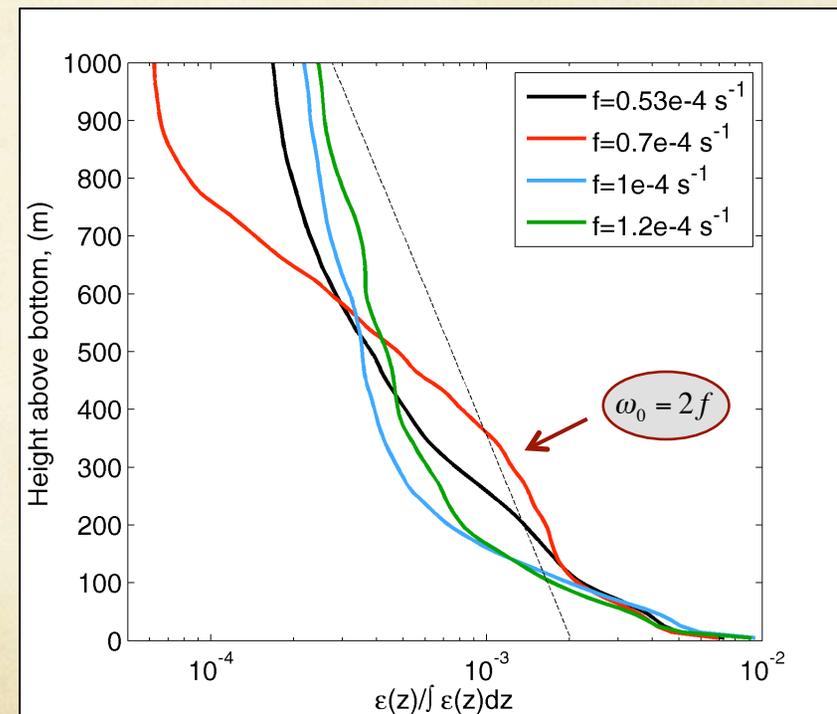
Energy dissipation:

- decays away from topography faster than exponential shape.
- more bottom trapped for steeper topography.

Energy dissipation rate:

$$\epsilon = E(x,y,t) \cdot q \cdot F(z)$$

energy conversion \rightarrow $E(x,y,t)$
 fraction of local dissipation, 1/3 \rightarrow q
 vertical structure \rightarrow $F(z)$



Conclusions

- ❑ Simulations reproduce energy dissipation observed in the Brazil Basin remarkably well suggesting that enhanced mixing in this region is maintained primarily by radiation and dissipation of internal tides.
- ❑ Energy is transferred from internal tides to the dissipation scales by the wave-wave nonlinear interactions.
- ❑ Prediction for the bottom energy conversion based on linear theory overestimates energy conversion from the super-critical topography.
- ❑ 30% of energy radiated by internal tides dissipates in the bottom 1-2 km.
- ❑ Energy dissipation decays away from topography faster than suggested by parameterization of Simmons et al, 2003.