Energetics of high frequency internal tides in global HYCOM

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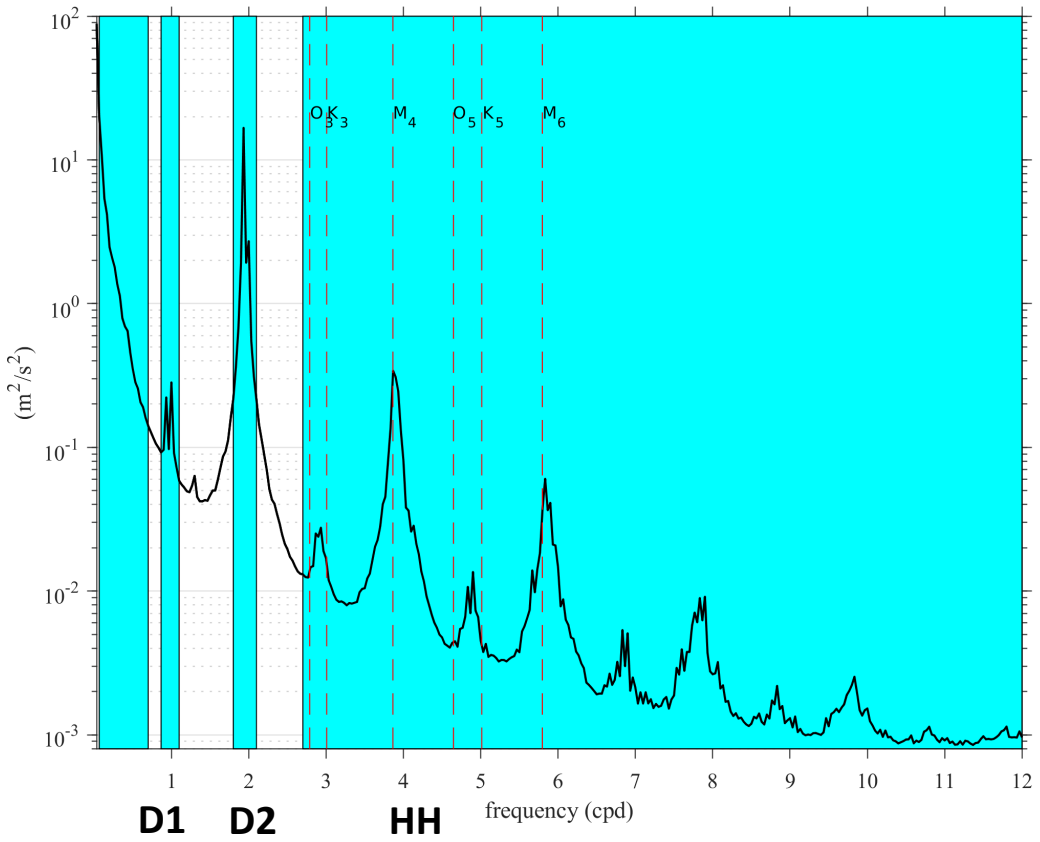
Model and Methods

Energy spectra at Amazon Shelf



Hybrid Coordinate Ocean Model (HYCOM)

- $1/25°$ (4 km) horizontal resolution, 41 vertical levels
- 3 hourly winds
- Tide forcing (M_2, S_2, N_2, K_1, O_1)
- No data assimilation

Analysis

- Analyze hourly 3D fields for **30 days of May/June 2019**
- Band-pass for semidiurnal (**D2**) and diurnal (**D1**) bands
- Capture the supertidal band (**HH**) via a high-pass
- Conduct **baroclinic energy analysis** in deep ocean (<250m)
- **Coarse graining** to estimate nonlinear energy transfer to HH

Research questions

Why are internal tides observed to steepen in global HYCOM $(1/25°)$?

Can HYCOM simulate these solitary NLIW?

*How much energy is transferred from tidal to supertidal frequencies in global ocean models?

Internal tides: sources and sinks

Time-mean and depth-integrated energy balance

Tidal (D1+D2) $C = \nabla \cdot F + R$

Supertidal (HH) $C = \nabla \cdot F + R$

Barotropic to baroclinic energy conversion $C = \overline{\rho' g W}$

Baroclinic energy flux $F = \overline{\boldsymbol{u}' p'} + \overline{\boldsymbol{u} E}$

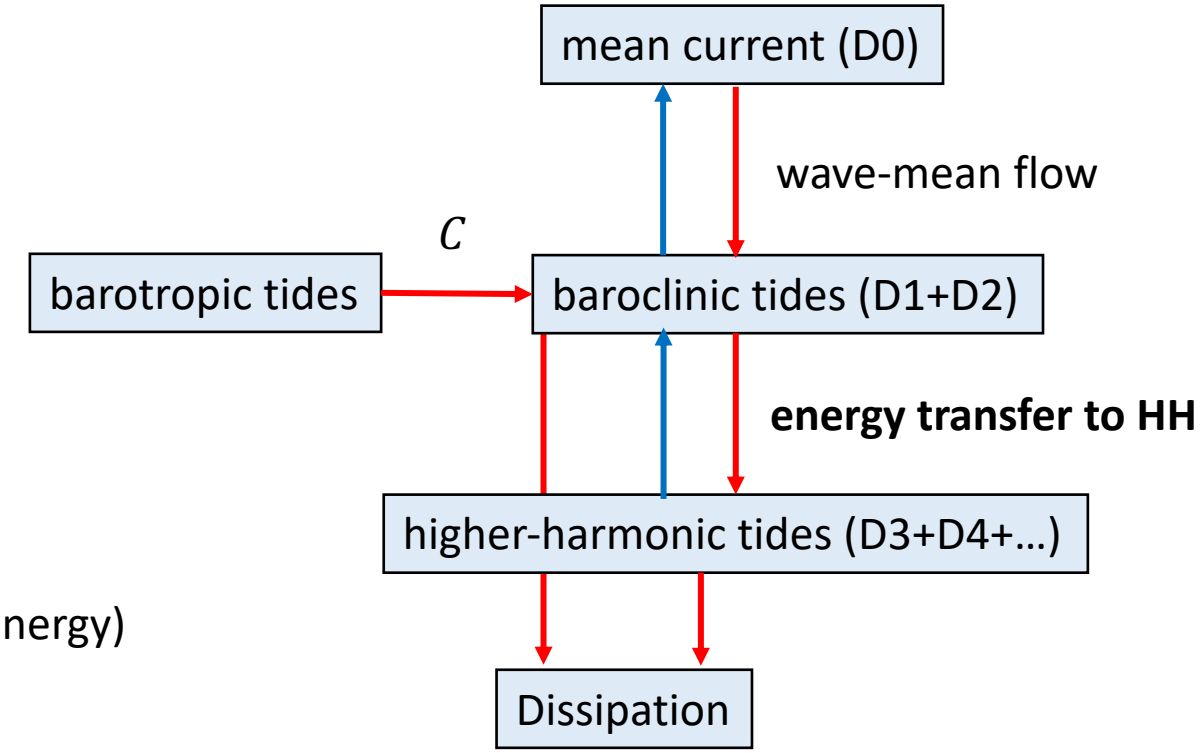
Residual

1. **Energy transfer to HH** (coarse-grained Kinetic Energy)

Π_τ $-\frac{1}{T}\int\int_0^h \rho_0 \left(\overline{u_i u_j} - \overline{u_i}\,\overline{u_j}\right)\frac{\partial \overline{u_j}}{\partial x_j} dz\, dt \qquad \tau = 9hr$

2. Wave-mean flow energy transfer

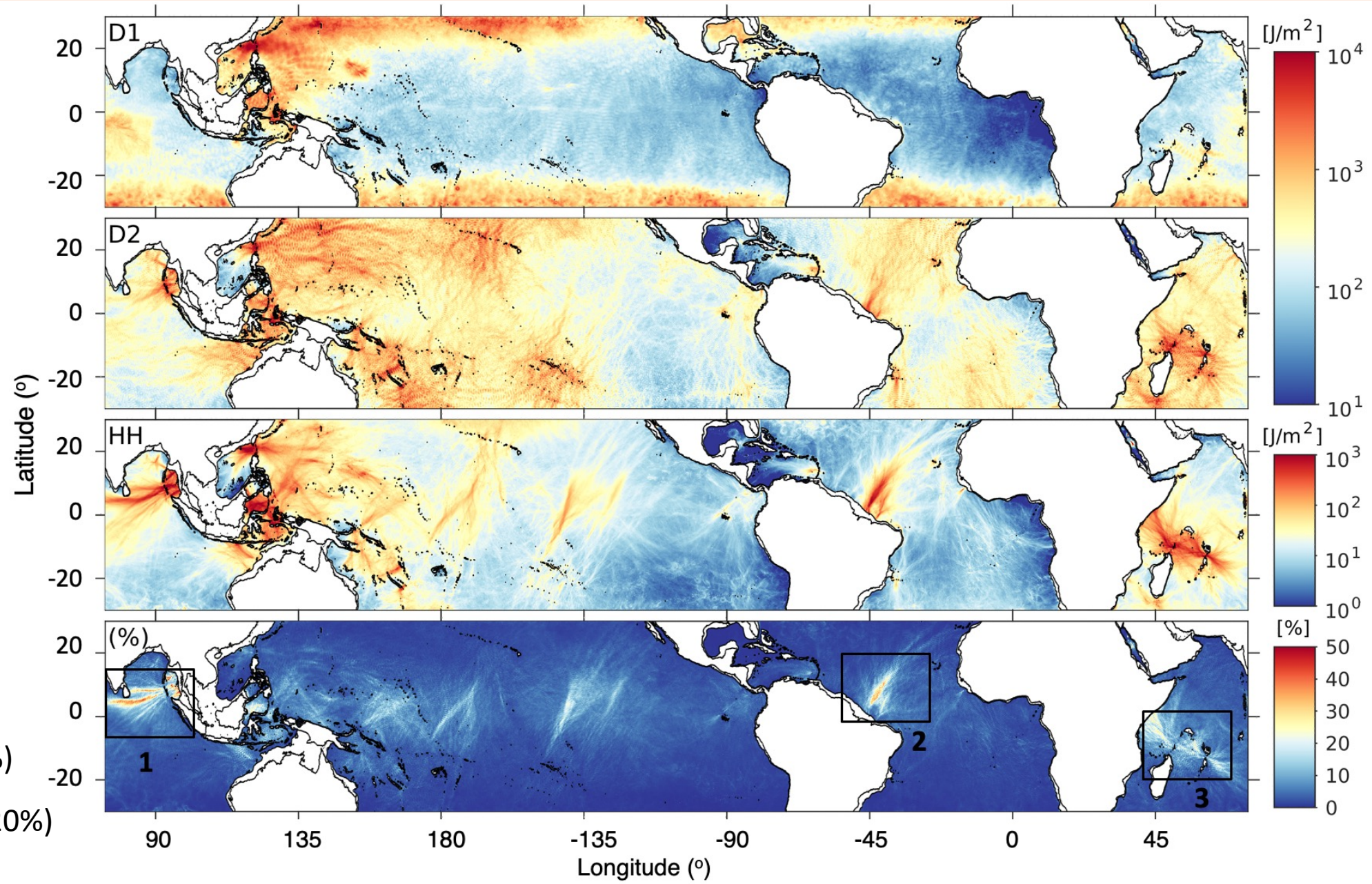
3. Dissipation



Baroclinic Kinetic Energy

Kinetic Energy

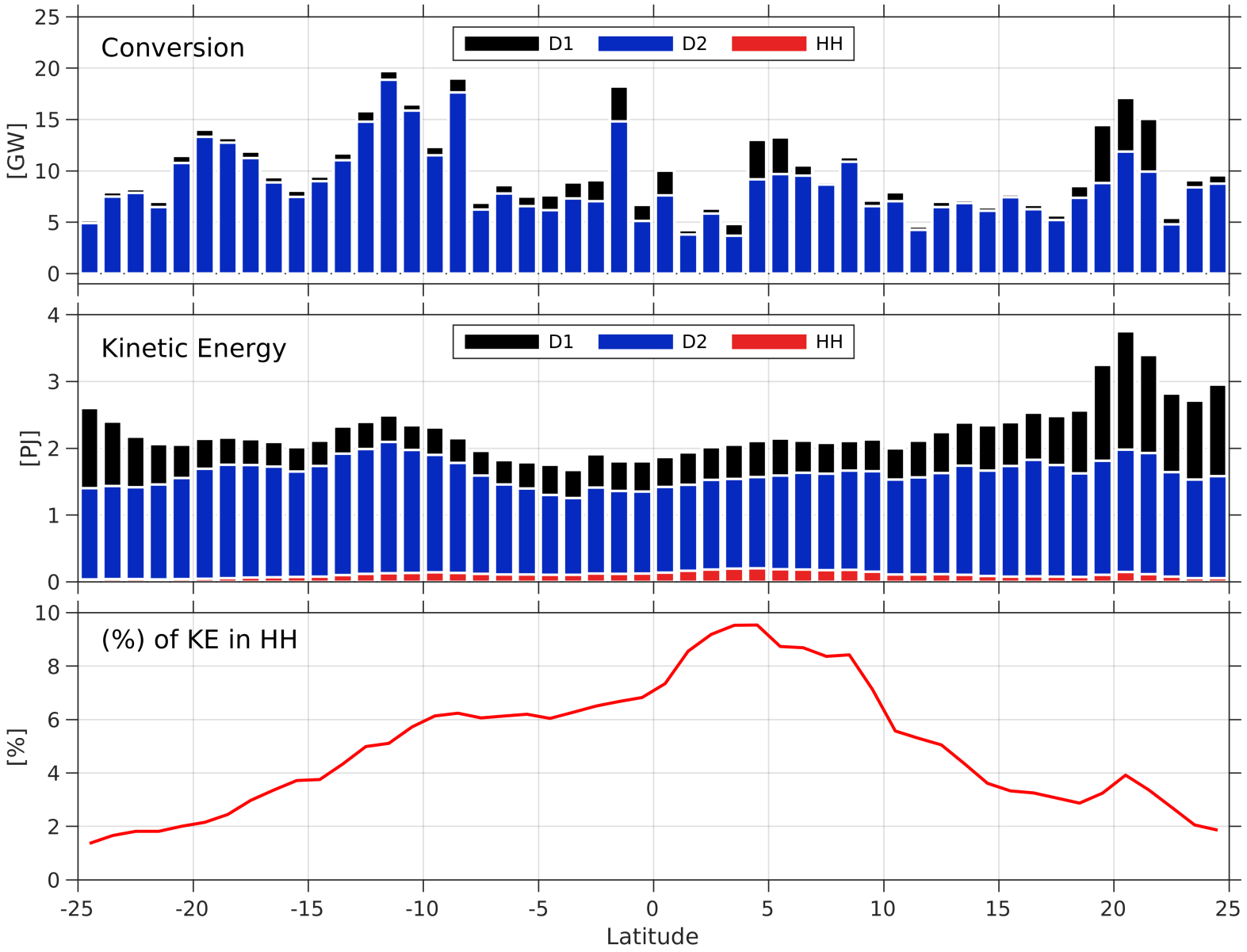
$$\frac{1}{2}\rho_0 \int_{-h}^{0} (u'(z)^2 + v'(z)^2) dz$$



Regions of high HH KE

1. Bay of Bengal (50%)
2. Amazon Shelf (30-40%)
3. Mascarene Ridge (15-20%)

Zonal Integrals



Conversion

(D1) = 60 GW

(D2) = 440 GW

(HH) = -2 GW

Kinetic Energy

(D1) = 31.67 PJ (IT + NIW)

(D2) = 76.14 PJ

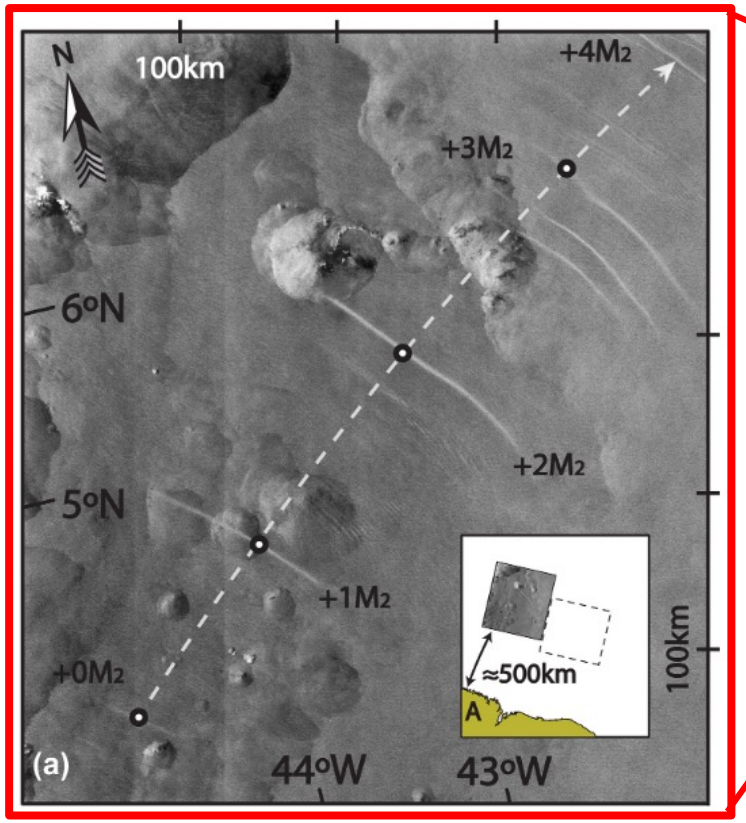
(HH) = 5.42 PJ (~5%)

Conversion does not explain the generation of higher-harmonics

HH KE accounts for 5% of IT energy on average, increasing to 10% at the equator

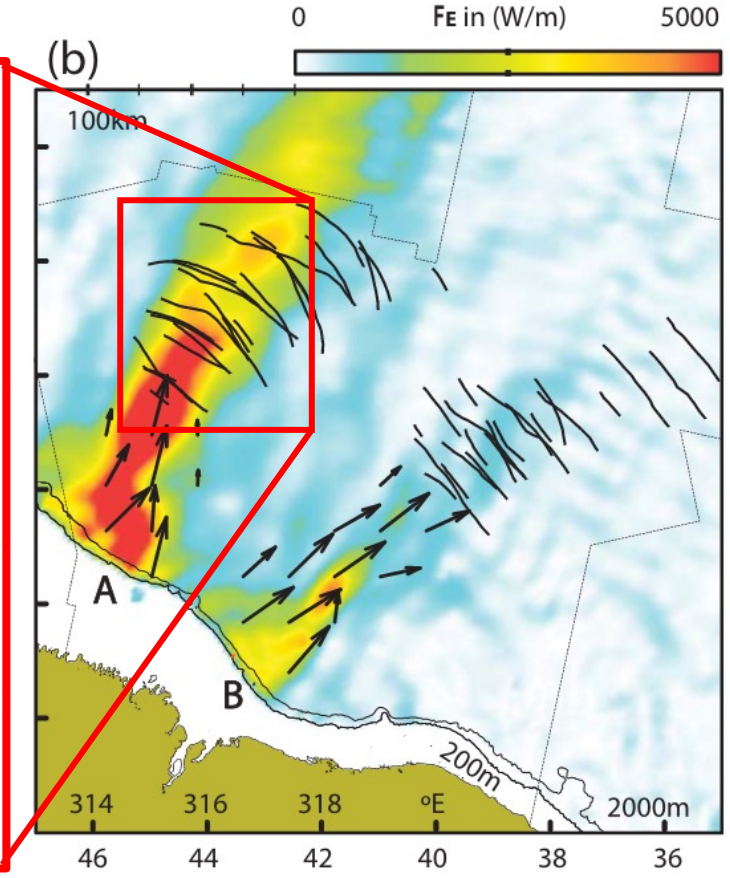
Internal Tide Steepening

Satellite
Solitary waves at Amazon Shelf

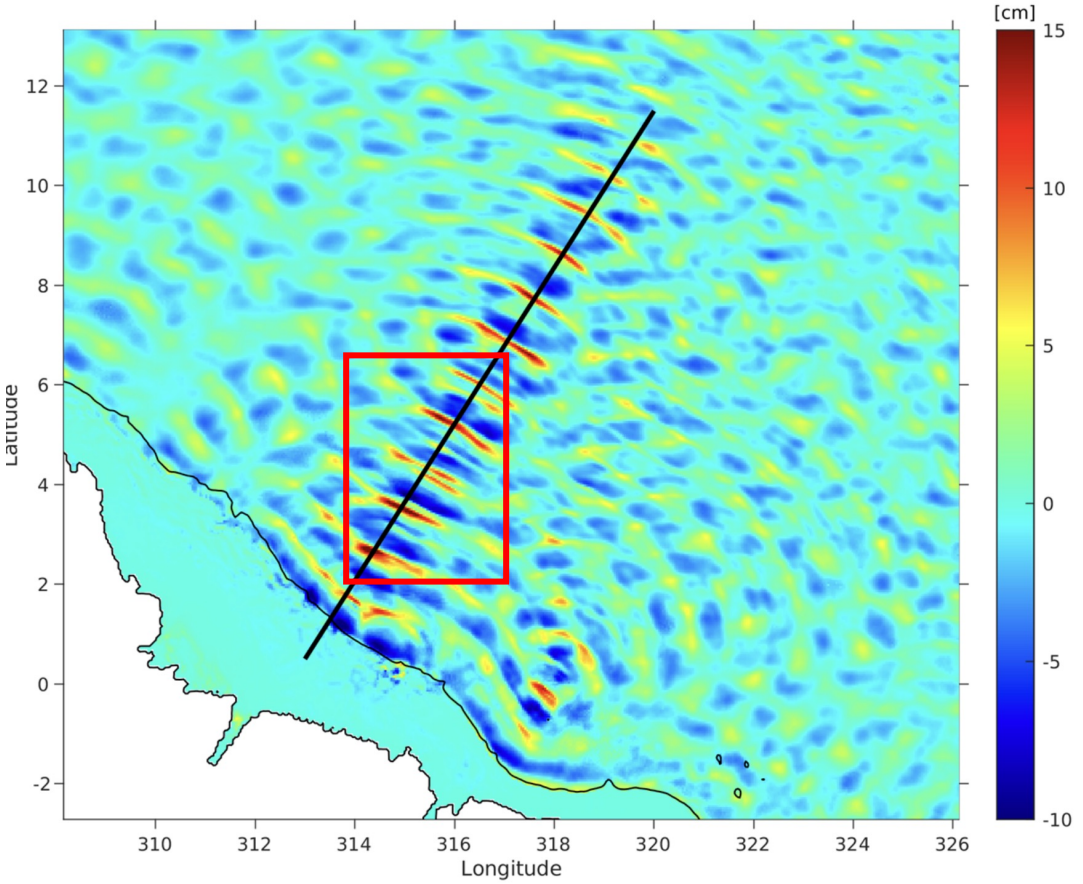


Magalhaes et al. (2016)

HYCOM
Energy fluxes (D1+D2) frequencies



HYCOM
Steric Sea Surface Height

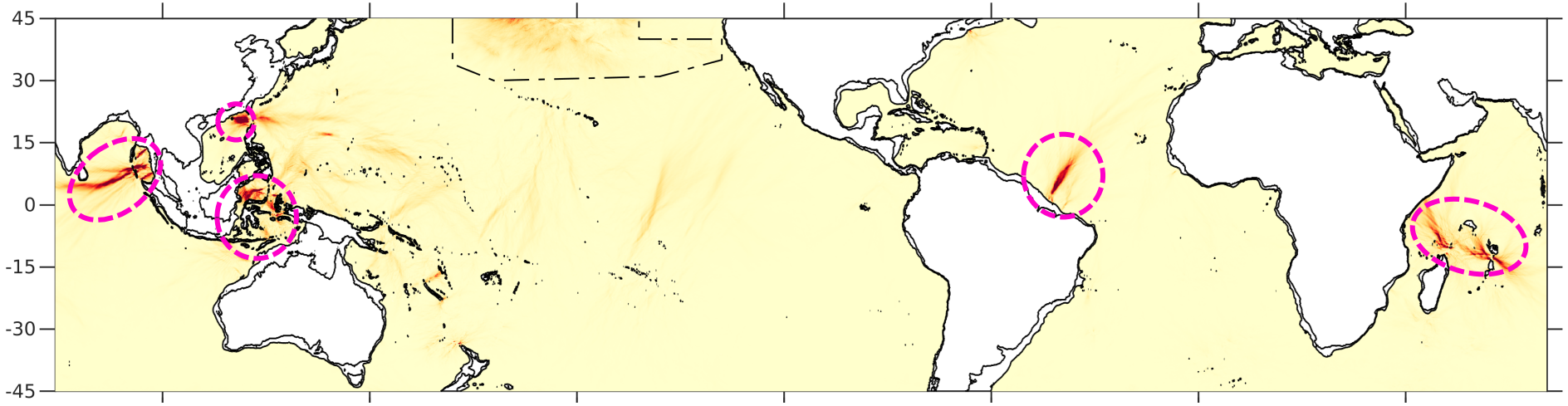


Nonlinear Internal Waves (NLIW)

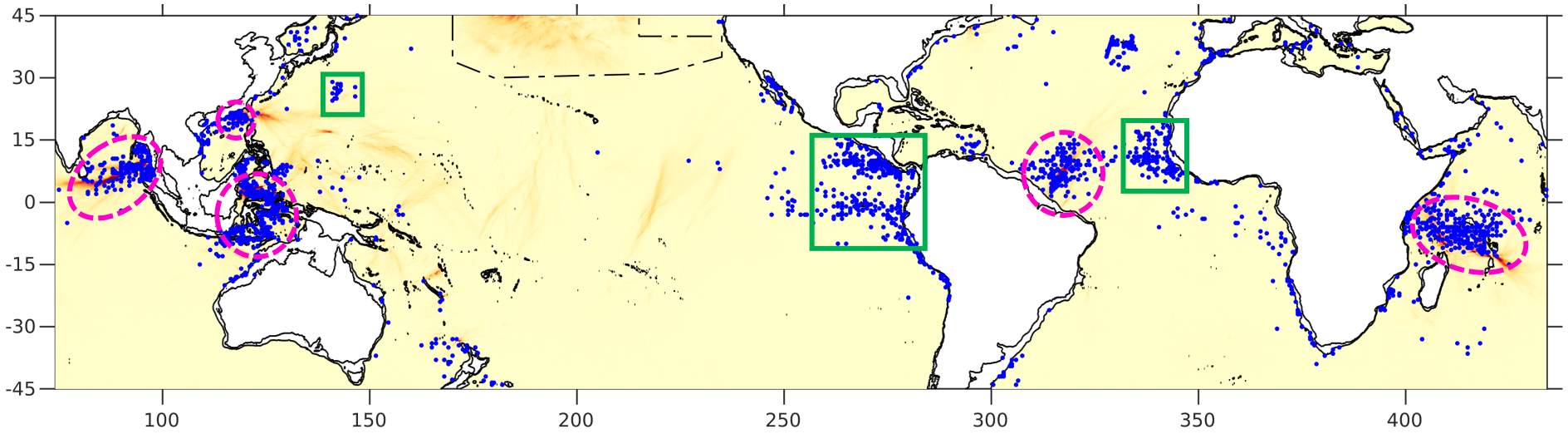
- Ellipses:
  strong HH fluxes
  (> 3 kW/m) coincide
  with observations of
  NLIW (solitons)

- Boxes:
  - Are these NLIW of
  *non*tidal origin?
  - Tidal generation sites
  are not well resolved?

Supertidal (HH) pressure flux in HYCOM



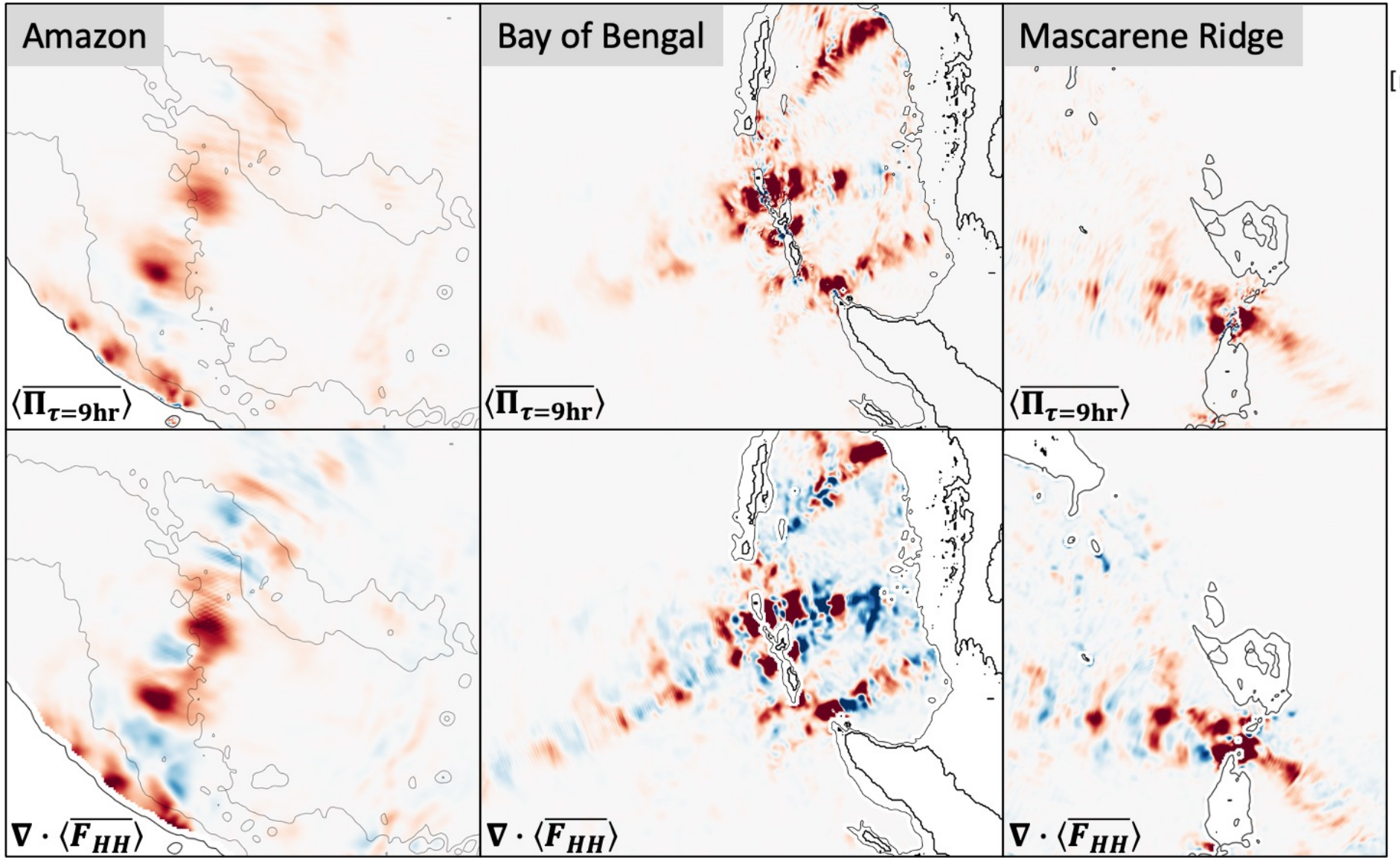
Location of NLIW observed in 250m resolution satellite imagery (Jackson et al. 2012)



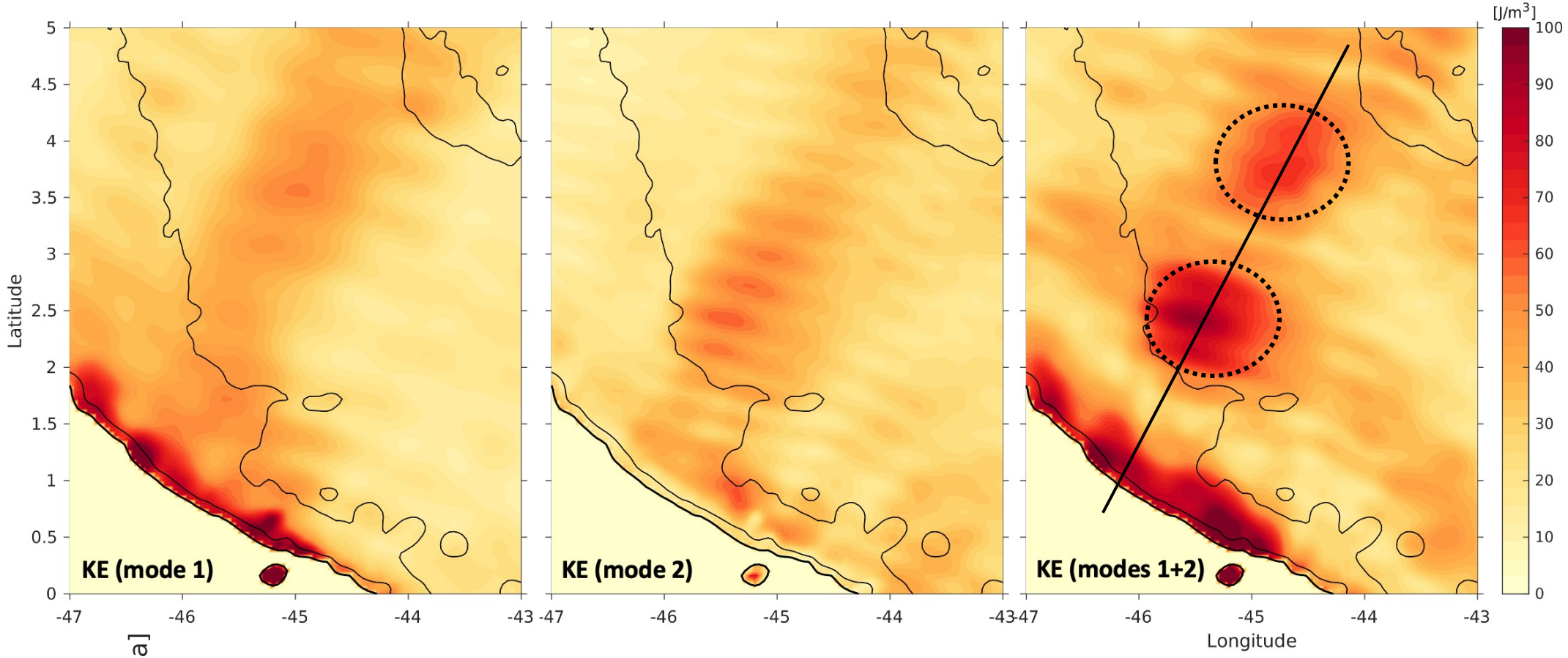
Nonlinear transfer to higher-harmonics

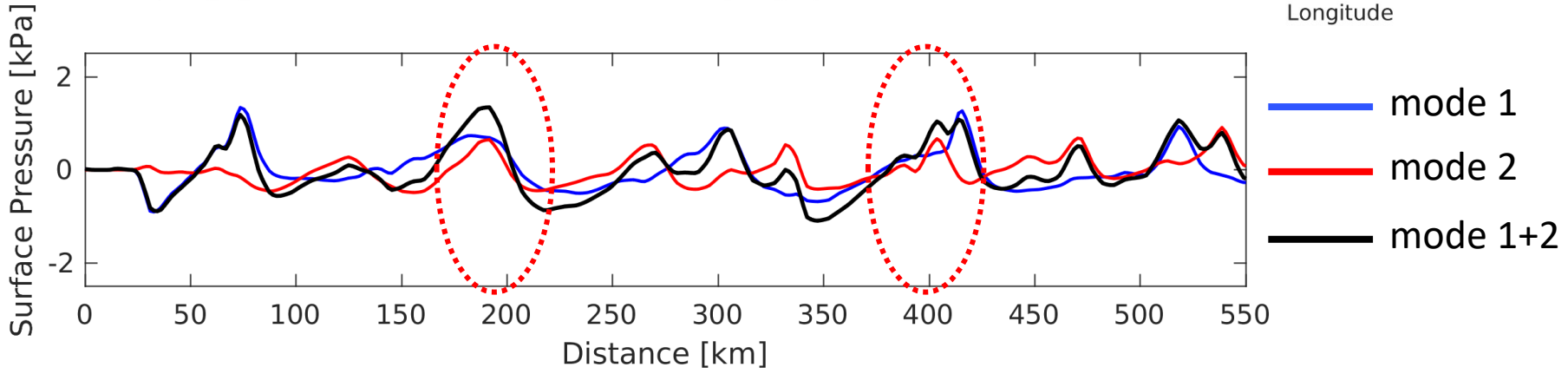
Nonlinear Energy transfer to HH (coarse-grained KE)

Supertidal energy flux divergence



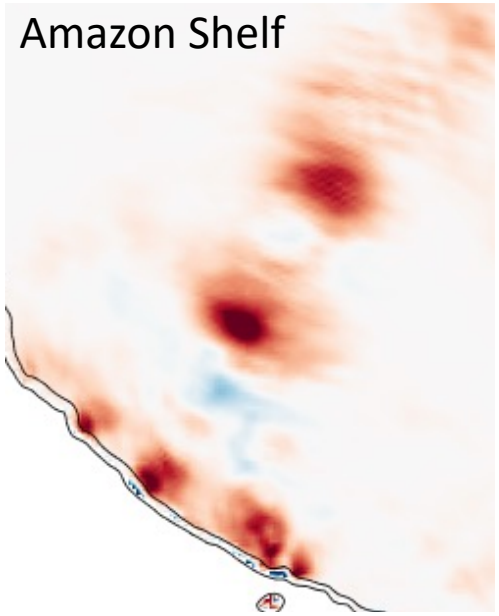
Vertical Mode Decomposition

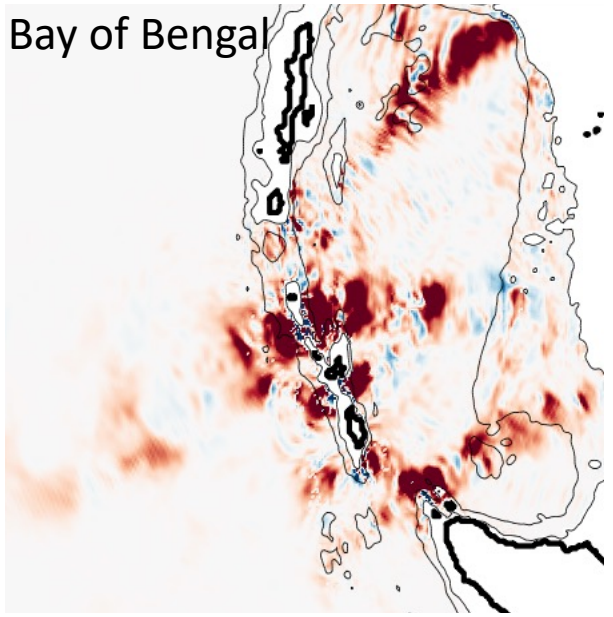




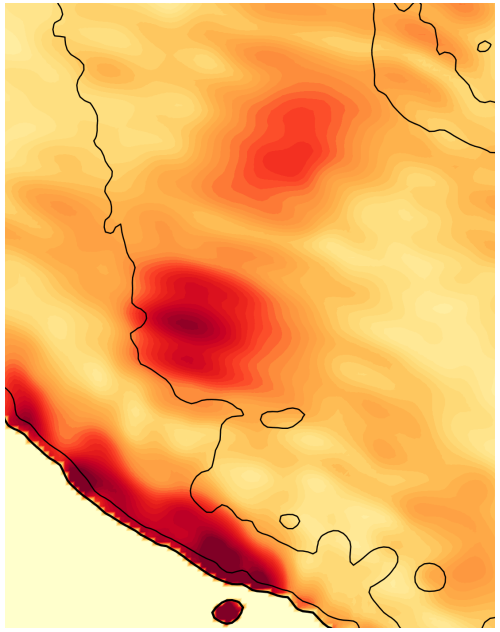
NLIW energy transfer – wave modes

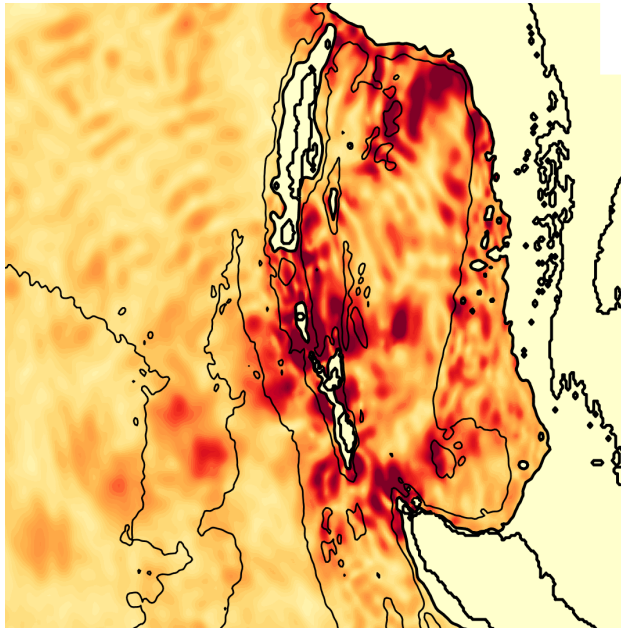
Nonlinear energy scale transfer to higher-harmonics

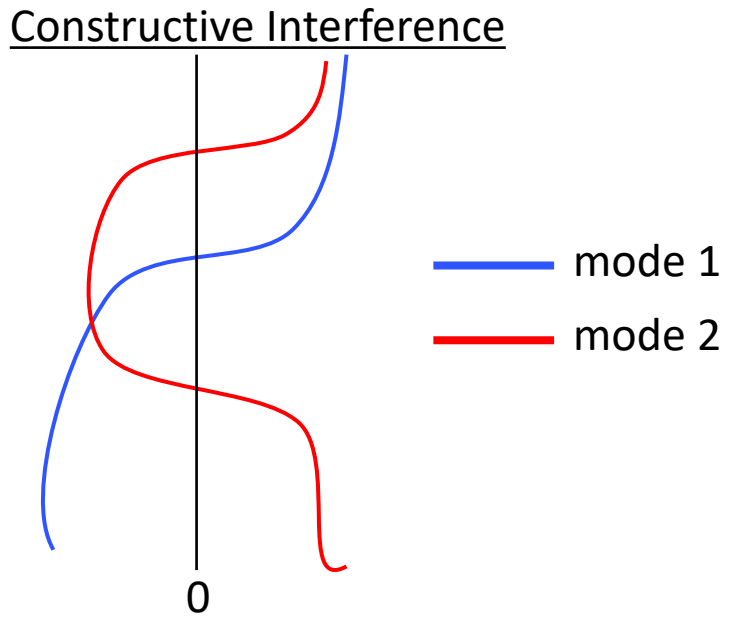


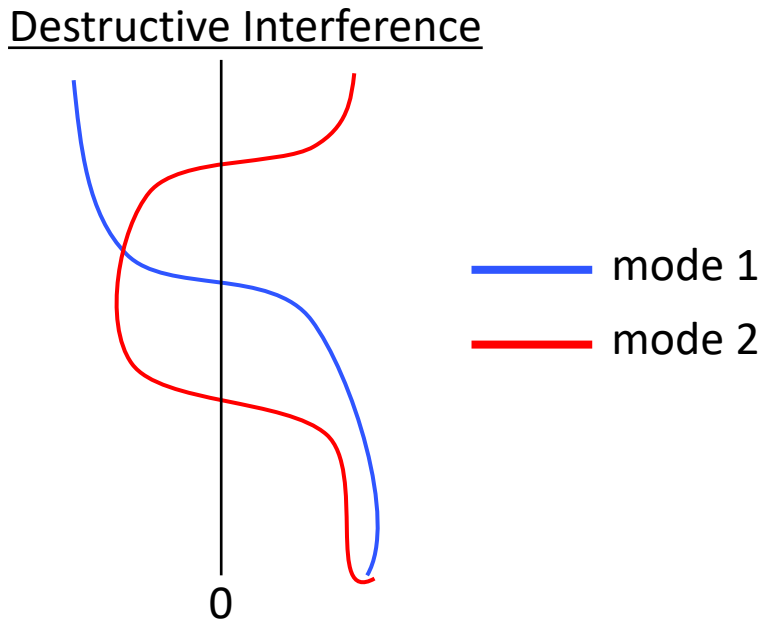


Surface Kinetic Energy for the superposition of modes 1 and 2

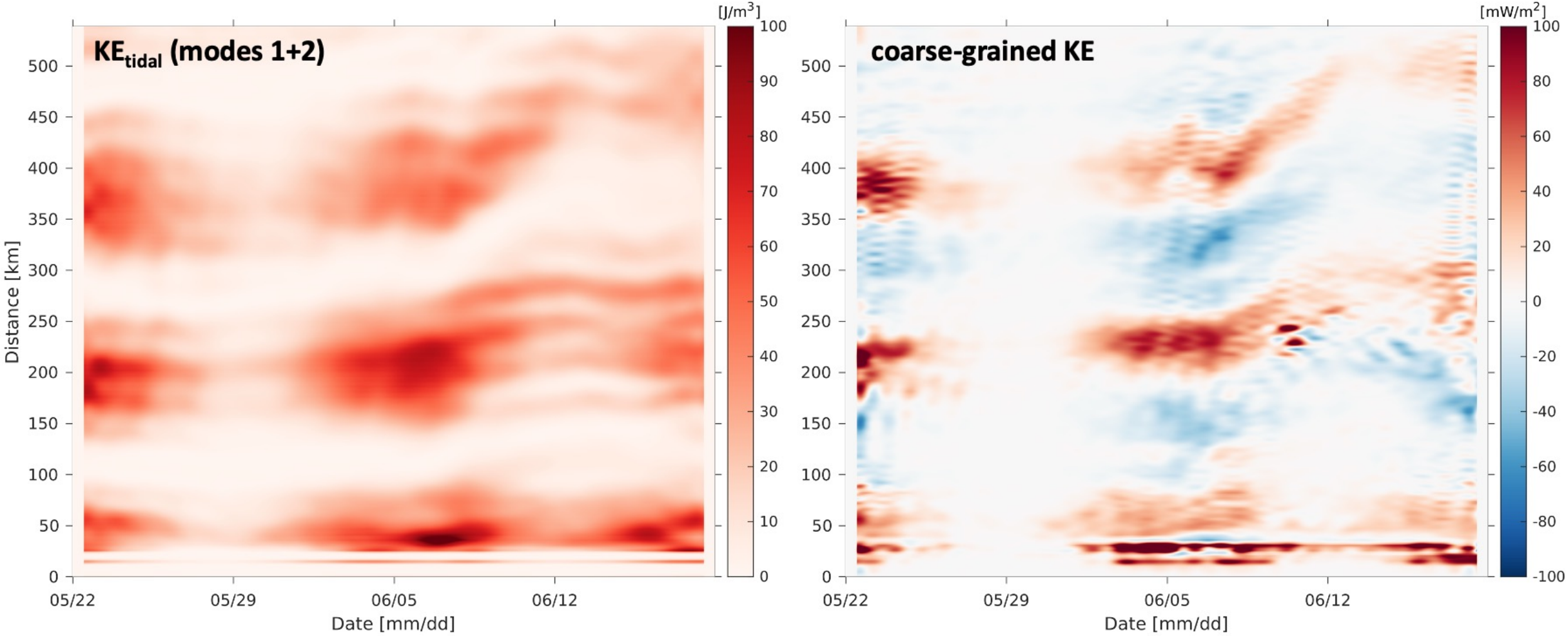








Spatial and temporal modulation



NLIW energy transfer modulated by the spring-neap cycle and slowly-varying stratification changes due to large scale forcing

Are solitary waves resolved in HYCOM?

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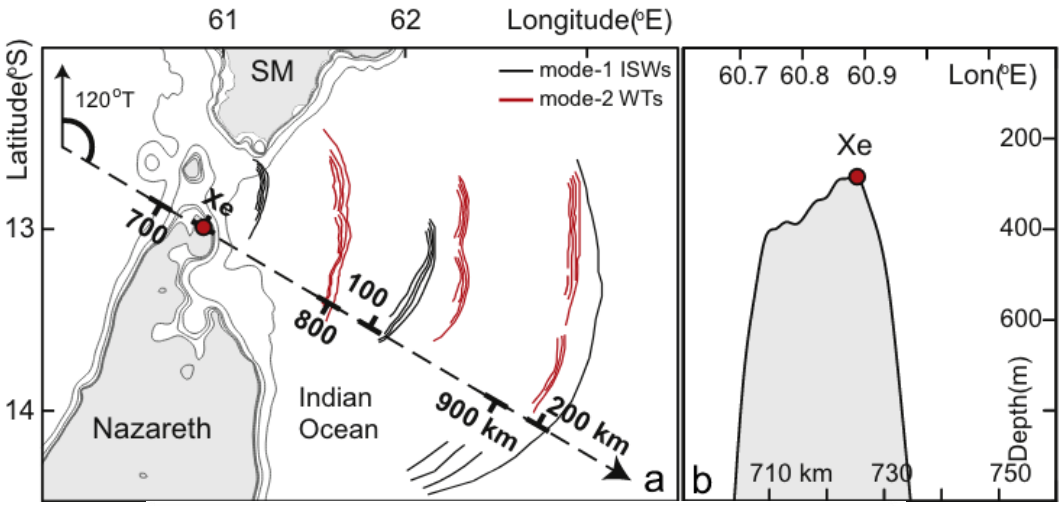
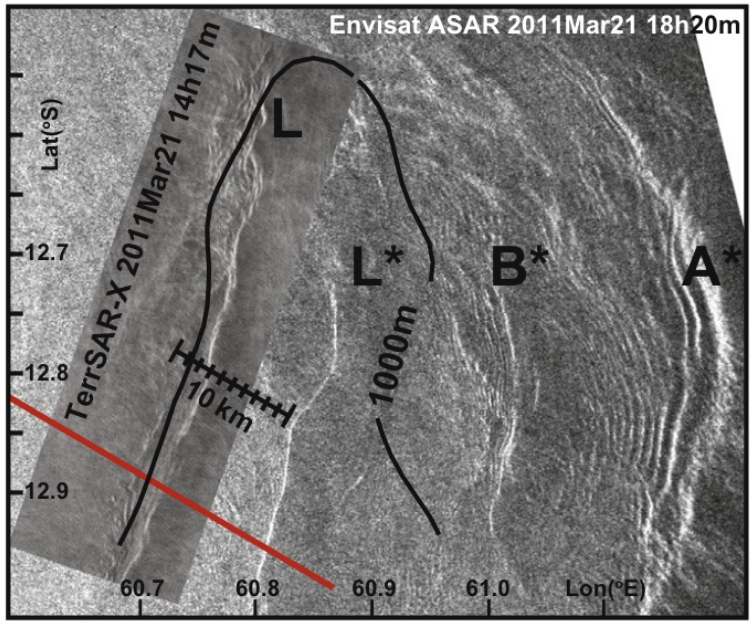
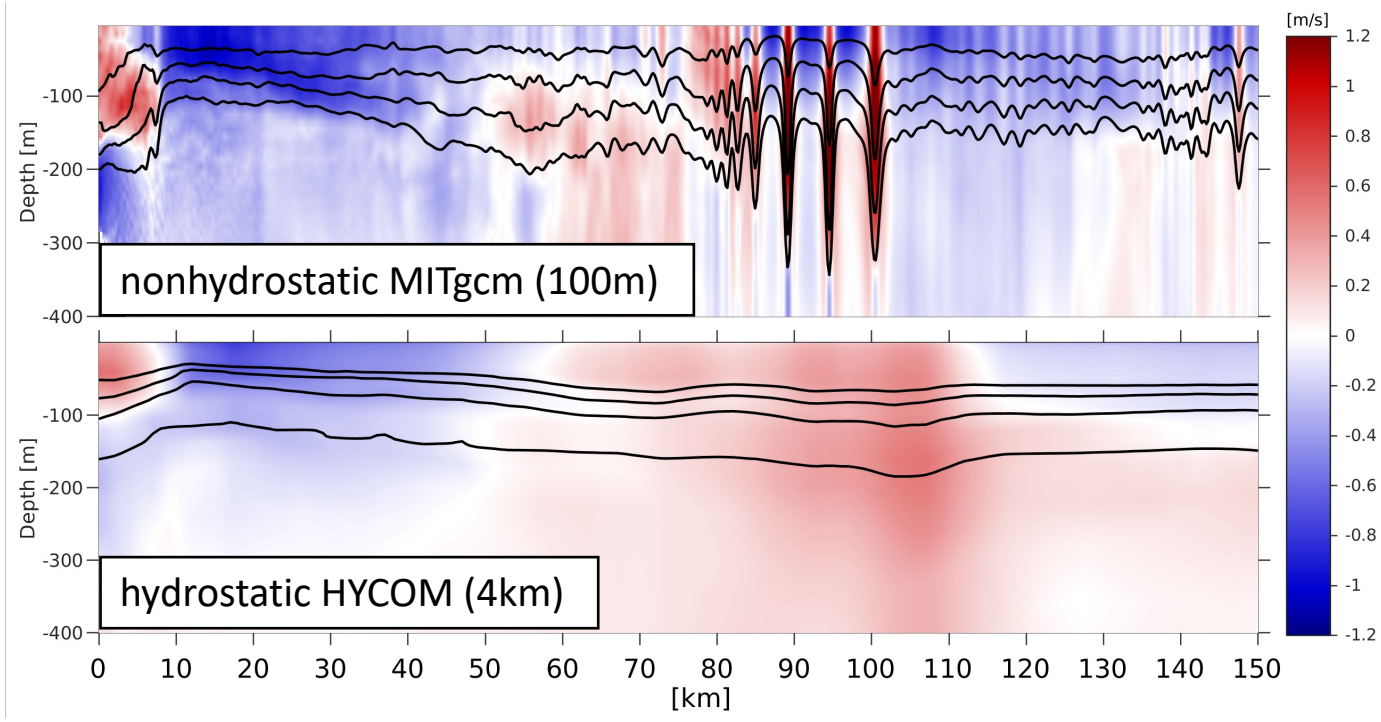
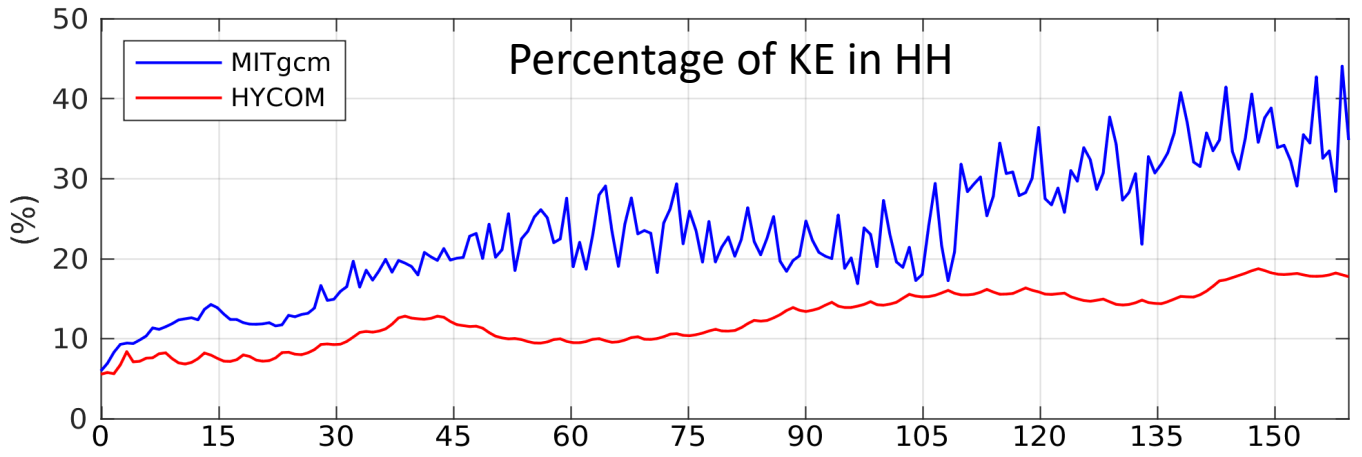
Solitary Waves at Mascarene Ridge (da Silva et al. 2015)









Summary

- At strong internal tide generation sites, supertidal energy constitutes 20-50% of the total internal tide energy
- Areas with high supertidal energy in HYCOM coincide with observations of nonlinear internal waves (NLIW)
- NLIW energy transfer to supertidal frequencies reveals a banding pattern, where the constructive interference of mode 1 and mode 2 internal tides results in the steepening of the internal tide
- Globally, internal tides transfer a net 40GW to HH within $\pm 25°$
- At current horizontal grid resolution (~ 4 km), these numbers may not be accurate, as solitary waves are not well resolved