The decay of the low-mode internal tide due to near-resonant wave-wave interactions

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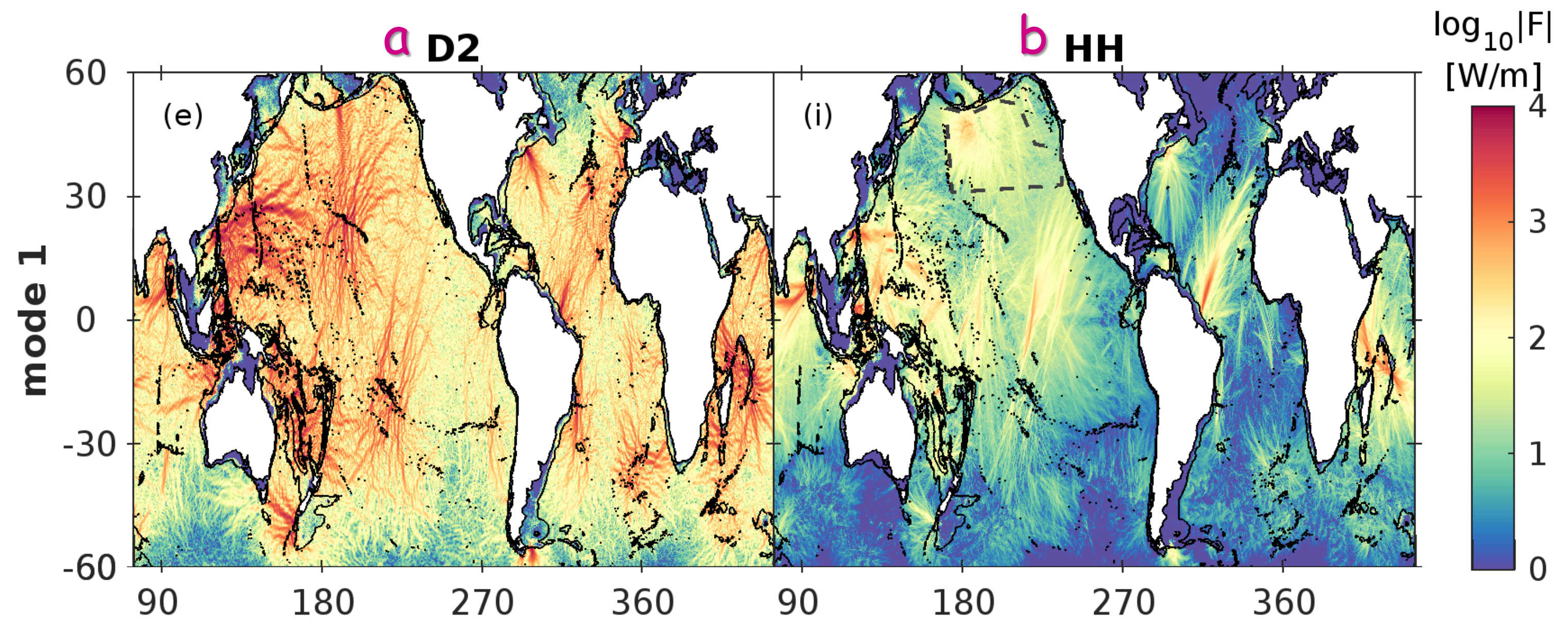

- Nonlinear steepening is a wave-wave interaction mechanism that has been understudied in global simulations.
- **How well is this mechanism represented in global simulations?**
- (a) In global 4-km HYCOM simulations, semidiurnal (D2) mode 1 energy is ubiquitous in the global ocean.
- (b) Supertidal (HH) energy mainly occurs in the tropics.

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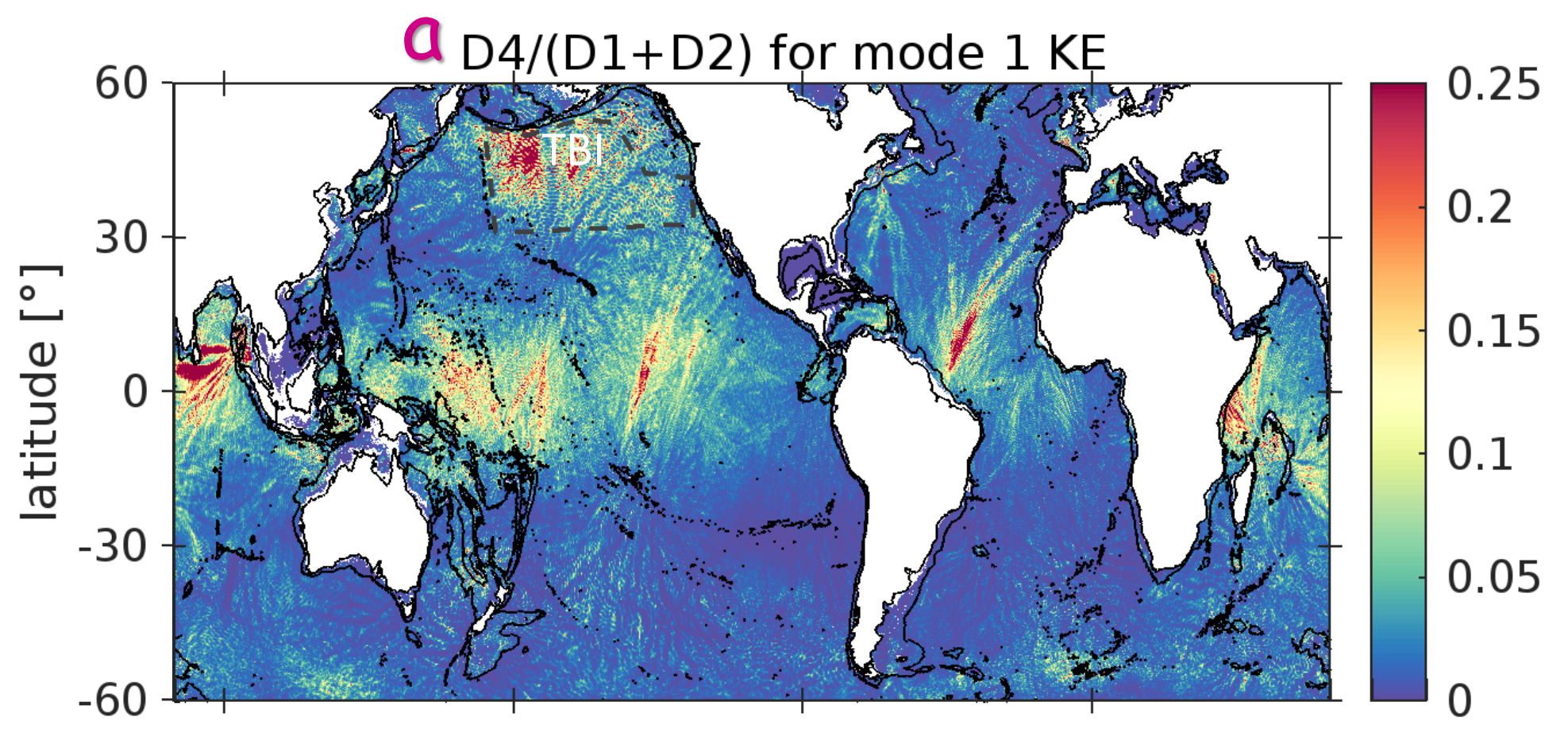
- (a) The ratio between supertidal and tidal energy is enhanced in the tropics due to nonlinear energy transfers associated with nonlinear steepening.
- (b) Weakly nonlinear theory (e.g., Wunsch, 2017) predicts that resonant self interactions between M$_2$ parent waves (*a, b*) generate a dispersive M$_4$ child wave (*c*):

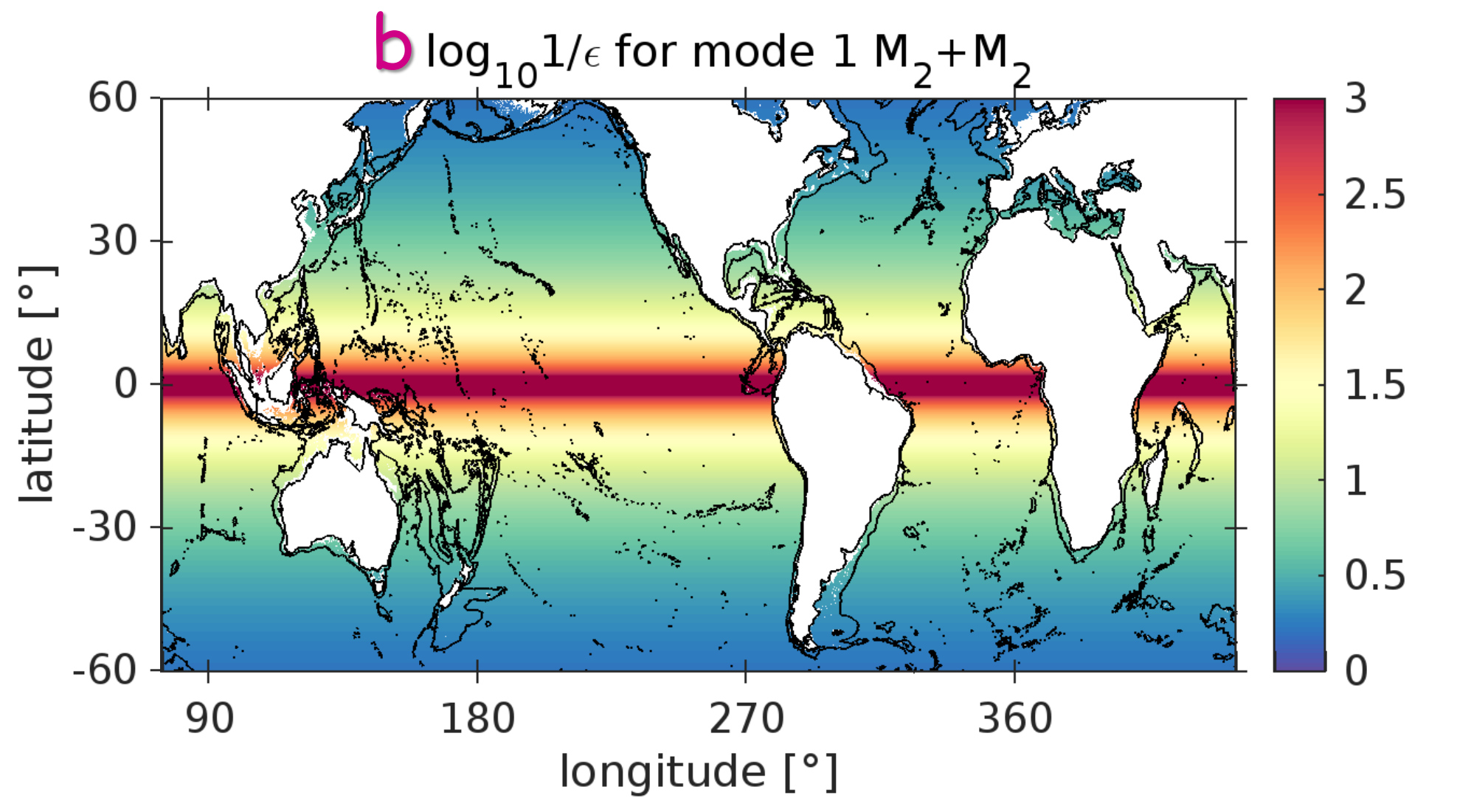
$$\mathbf{k}_a + \mathbf{k}_b = \mathbf{k}_c$$
$$\omega_a + \omega_b = \omega_c$$

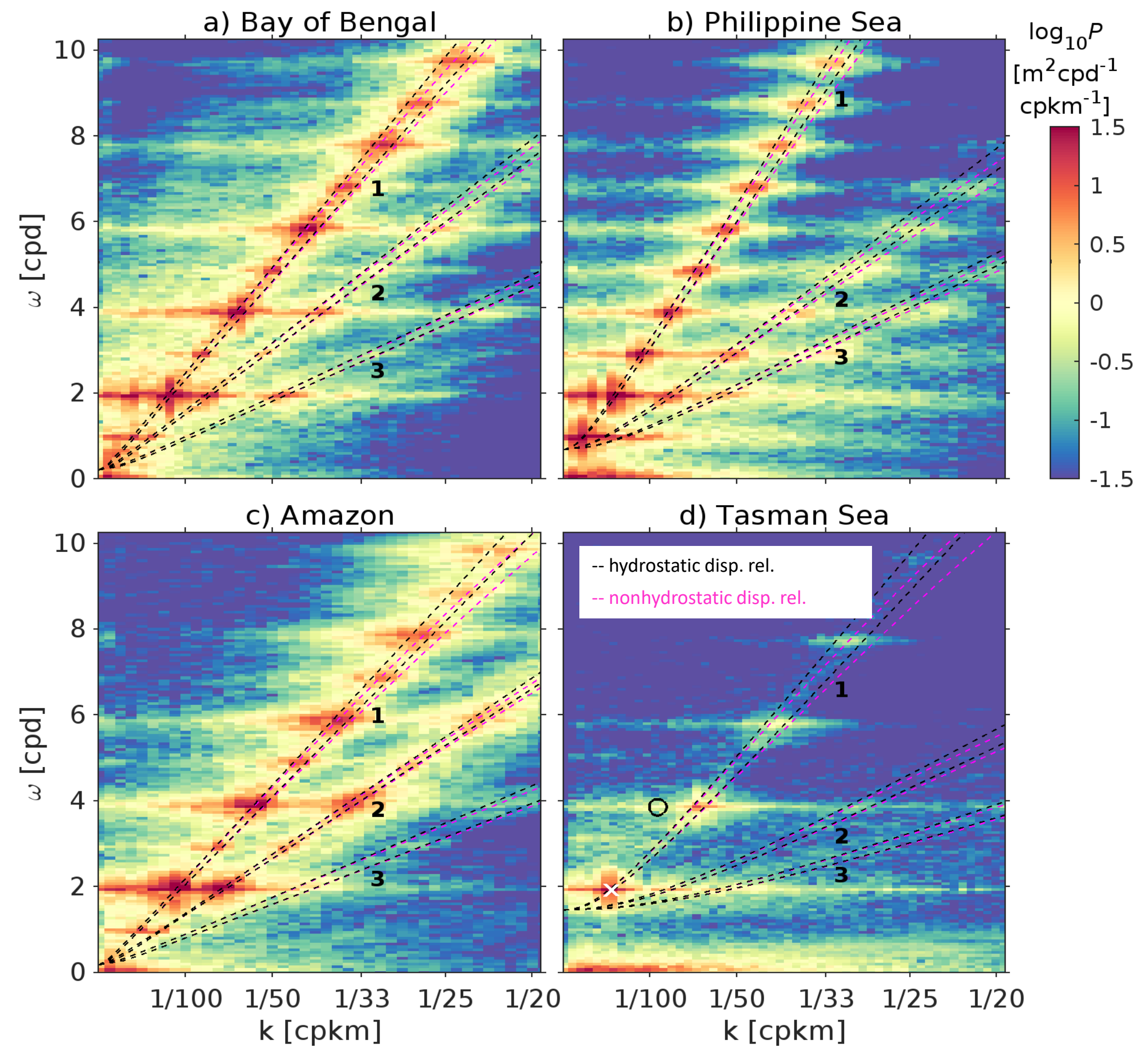
- The strength of the resonance is determined by

$$\epsilon = \frac{[\omega_a + \omega_b]^2 - \omega([k_a + k_b])^2}{[\omega_a + \omega_b]^2}$$

- Both model and theory show that the resonance ($1/\epsilon$) is a function of Coriolis frequency and stratification.







- The $k - \omega$ spectra along internal tide beams show that the supertidal energy projects on the higher harmonics of the tidal frequencies.
- The harmonics map onto the mode 1-3 dispersion curves $\omega^2 = f^2 + k_n^2 c_n^2$ at all sites.
- The harmonics contain less energy at higher latitudes, in agreement with the weakly nonlinear theory.
- **Do the harmonics contribute to the soliton shapes in (non)hydrostatic simulations?**

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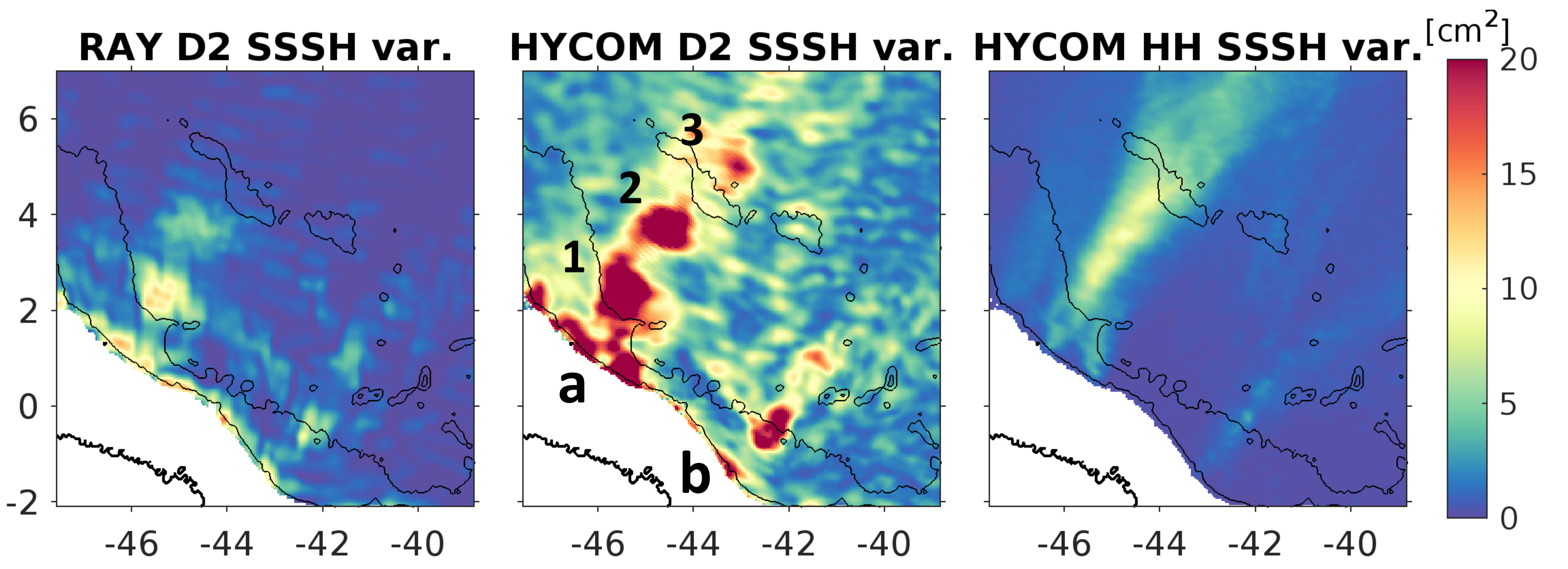

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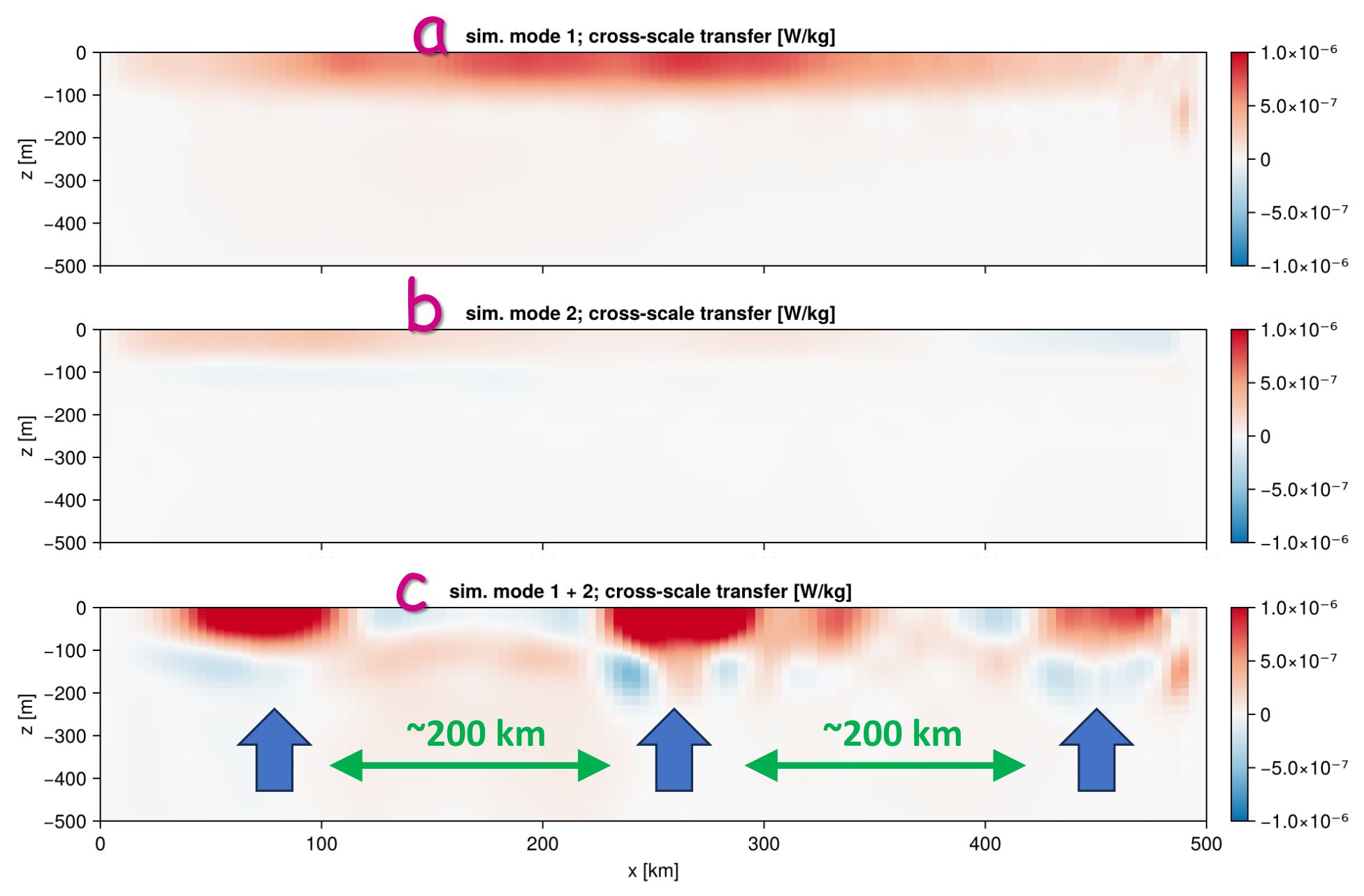
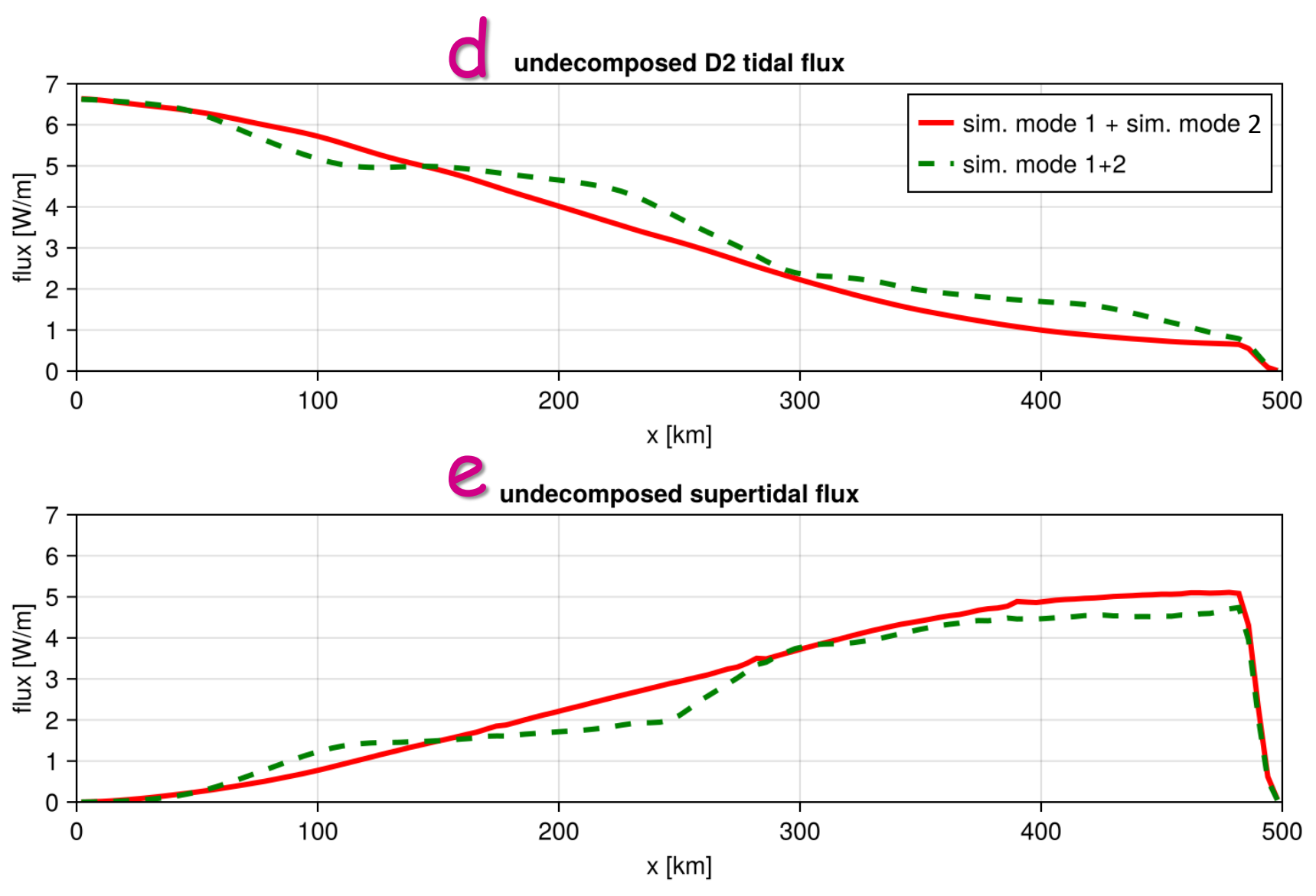
- At the AMAZON shelf, a site with strong supertidal energy, large semidiurnal (D2) SSSH variance occurs at regular spaced patterns (marked 1-3) along **a** and **b** beams in model and altimetry (R. Ray).
- These banding patterns are separated by ~200 km (mode-1 $L = 110$ km)
- A supertidal (HH) energy beam emerges from these patterns.
- The constructive interference between D2 mode 1 and mode 2 waves causes these patterns (Solano et al., 2023).
- **Do these mode 1+2 interactions reinforce the energy transfers, in addition to the mode 1 self interactions? This is discussed in panel 6.**





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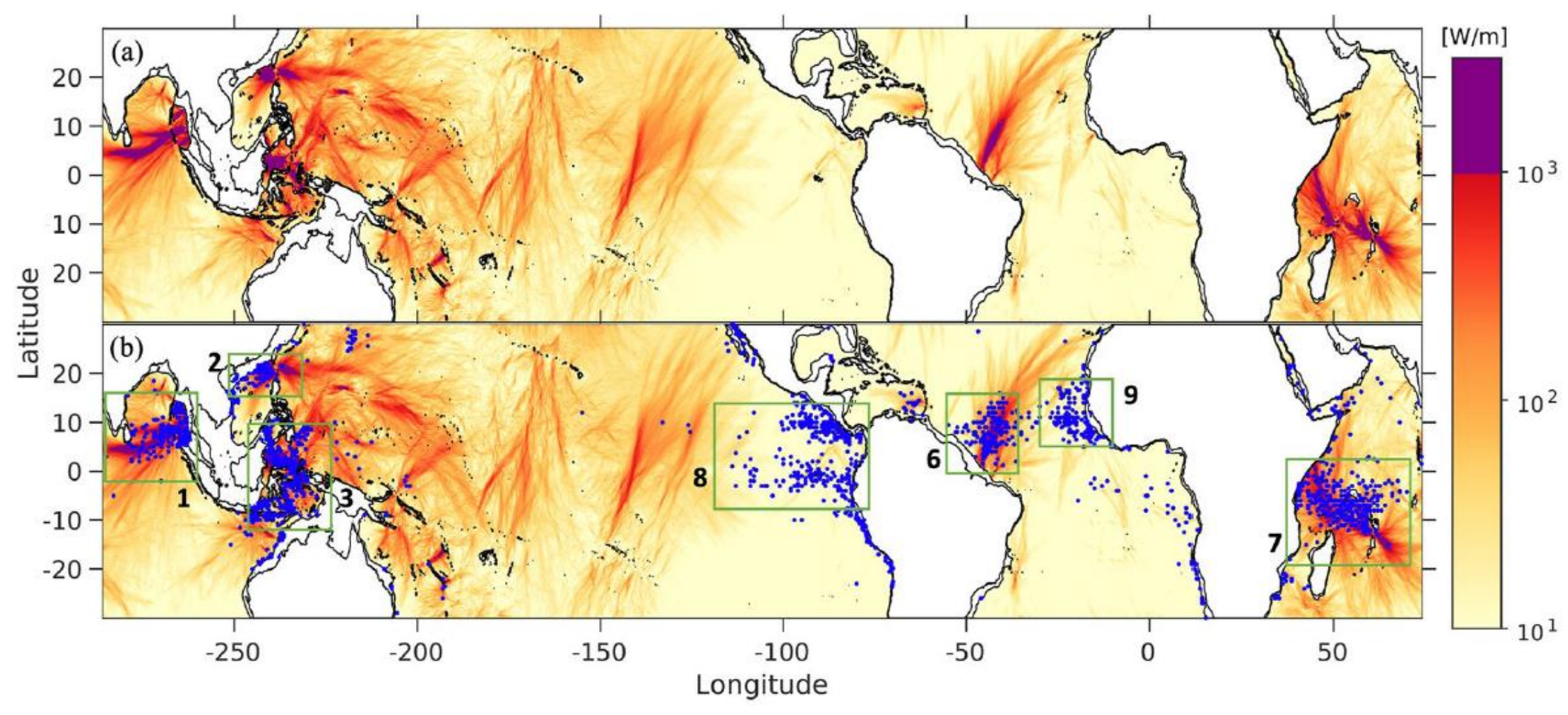
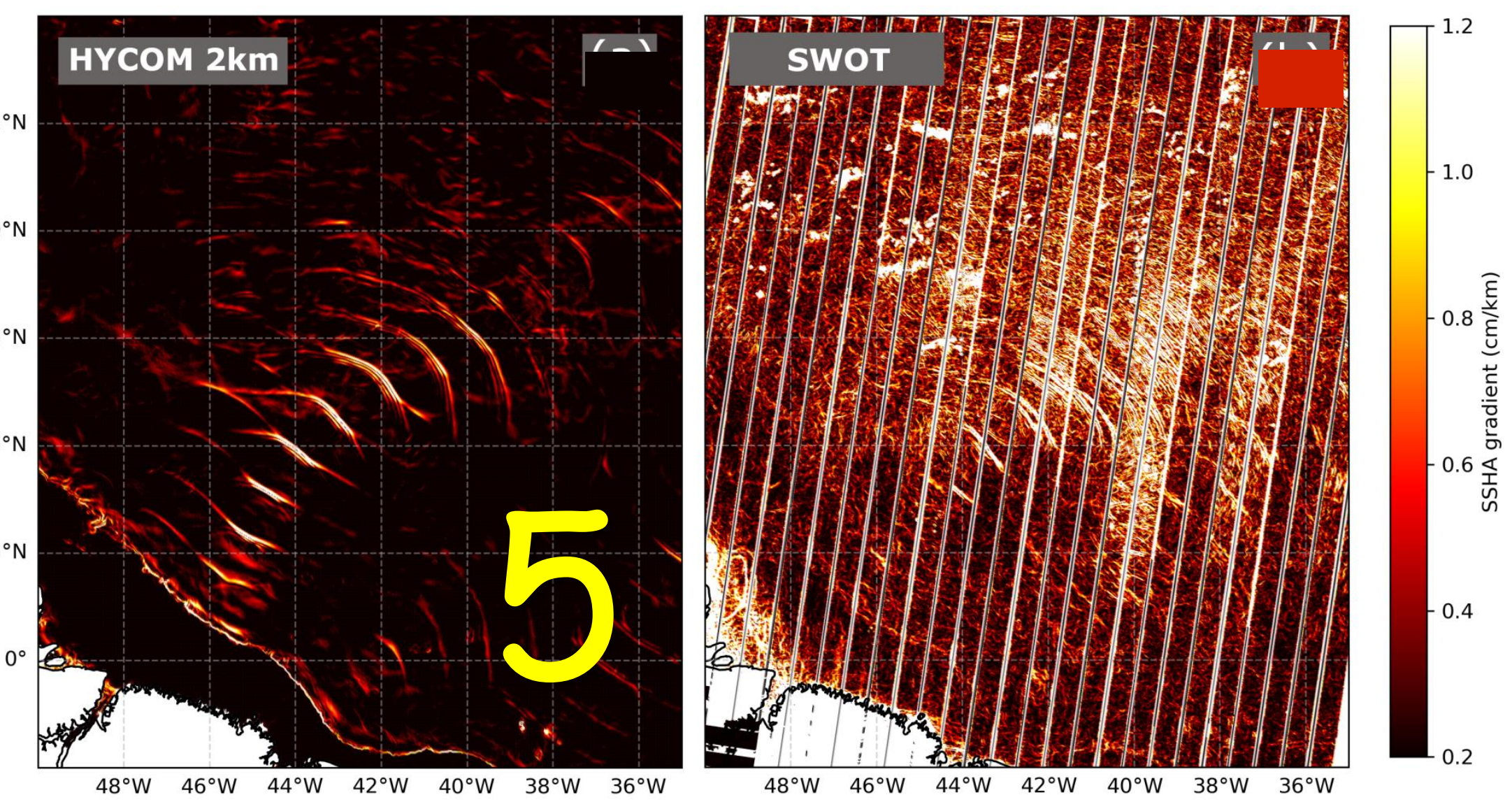
- We use *oceananigans.jl* to investigate the mode 1+2 interactions:
  - Realistic stratification of the Amazon
  - 2D channel: 500 km x 4000 m @ **0°** N
  - Δx=4 km (as in HYCOM) and 107 layers, Δz=5–40 m
  - 12-day forcing with an M$_2$ mode 1 and/or 2 wave
  - Nonhydrostatic model
- The results agree with HYCOM
- Energy is transferred to harmonics of M$_2$ (not shown).
- The mode 1+2 superposition changes the spatial distribution of
  - the coarse-grained KE transfers Π from tidal to supertidal band (a-c)
  - the tidal (d) and supertidal fluxes (e)
- However, the mode 1+2 interaction does not enhance the transect integrated supertidal energy.

a Supertidal fluxes (colors) and solitary waves (blue dots)



b Sea surface height gradient maps at the Amazon



- (a) In the Bay of Bengal (1), Luzon Strait (2), Amazon (6), and Mascarene Ridge (7), super-tidal energy fluxes exceed 1 kW/m.
- Here, we observe open ocean solitons in SAR images (blue dots; Jackson et al., 2013).
- (b) At the Amazon shelf (figure made by J. Wang) the solitons in 2-km HYCOM (FSU) appear closer to the coast and occur in a less noisy back-ground as compared to SWOT.

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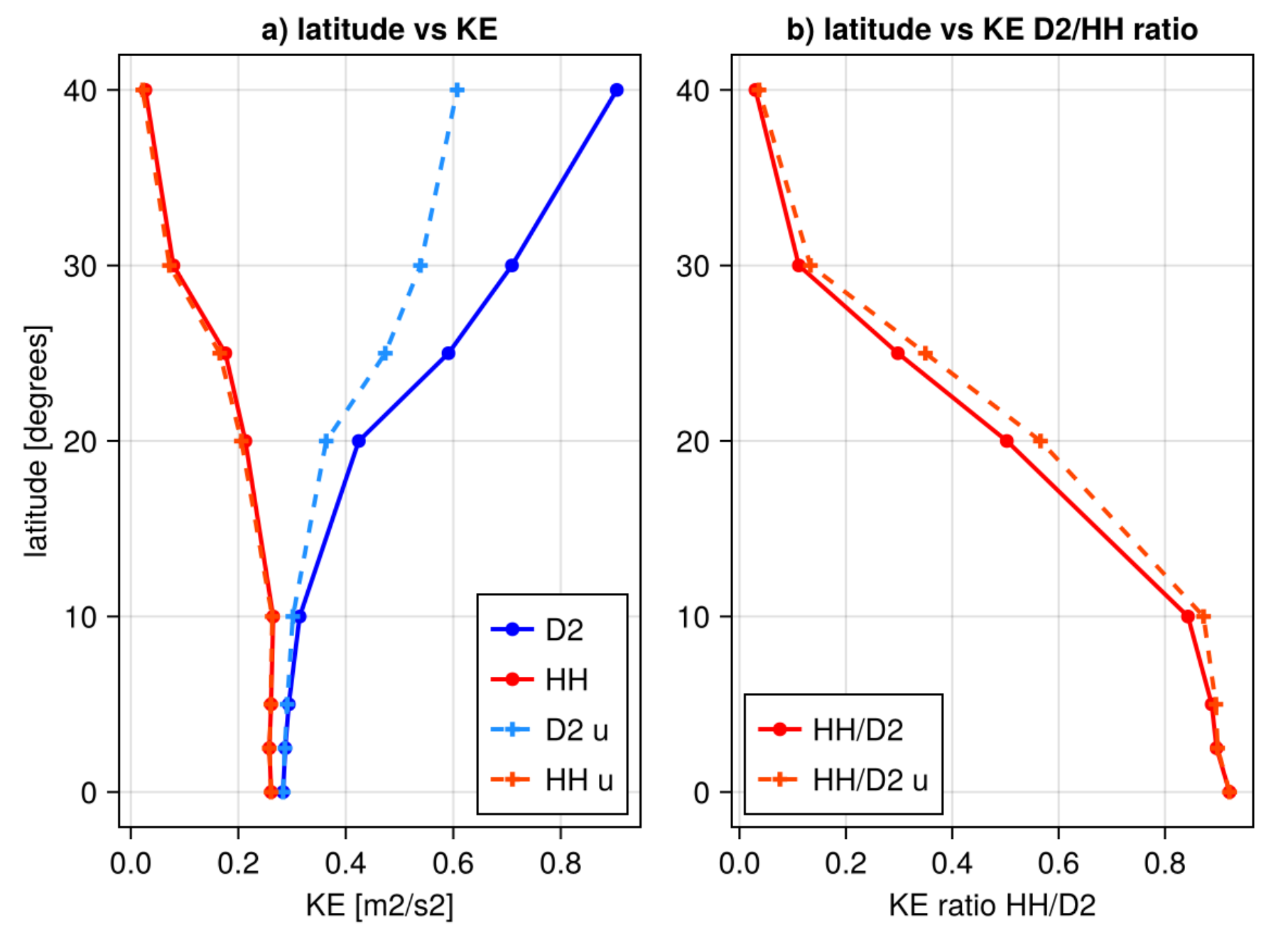
- We force an M$_2$ mode-1 wave at different latitudes.
- For higher latitudes
  - supertidal KE and HH/D2 ratio decrease in agreement with theory and HYCOM
  - D2 KE increases (because APE decreases; not shown)

This poster is based on these studies:

Buijsman, M.C., et al. (2025). Energetics of (super)tidal baroclinic modes in a realistically forced global ocean simulation. Journal of Geophysical Research: Oceans, 130, e2025JC022460, https://doi.org/10.1029/2025JC022460.

Solano, M. S., Buijsman, M. C., et al. (2023). Nonlinear internal tides in a realistically forced global ocean simulation. Journal of Geophysical Research: Oceans, 128, e2023JC019913. https://doi.org/10.1029/2023JC019913



Conclusions

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- In agreement with theory, mode-1 M$_2$ self interactions are enhanced in the tropics in global and idealized simulations due to small rotation and surface intensified stratification.
- The energy transfers occur in regular spaced banding patterns, in which mode 1 and 2 waves constructively interfere.
- While these mode 1+2 interactions modulate the transfers in space, these interactions are not resonant, and they do not increase the net transfers.
- **Plans**: rerun oceanigans.jl for $\Delta x \approx O(100)$ m to study the energy transfers and the relation between the harmonics and solitons.