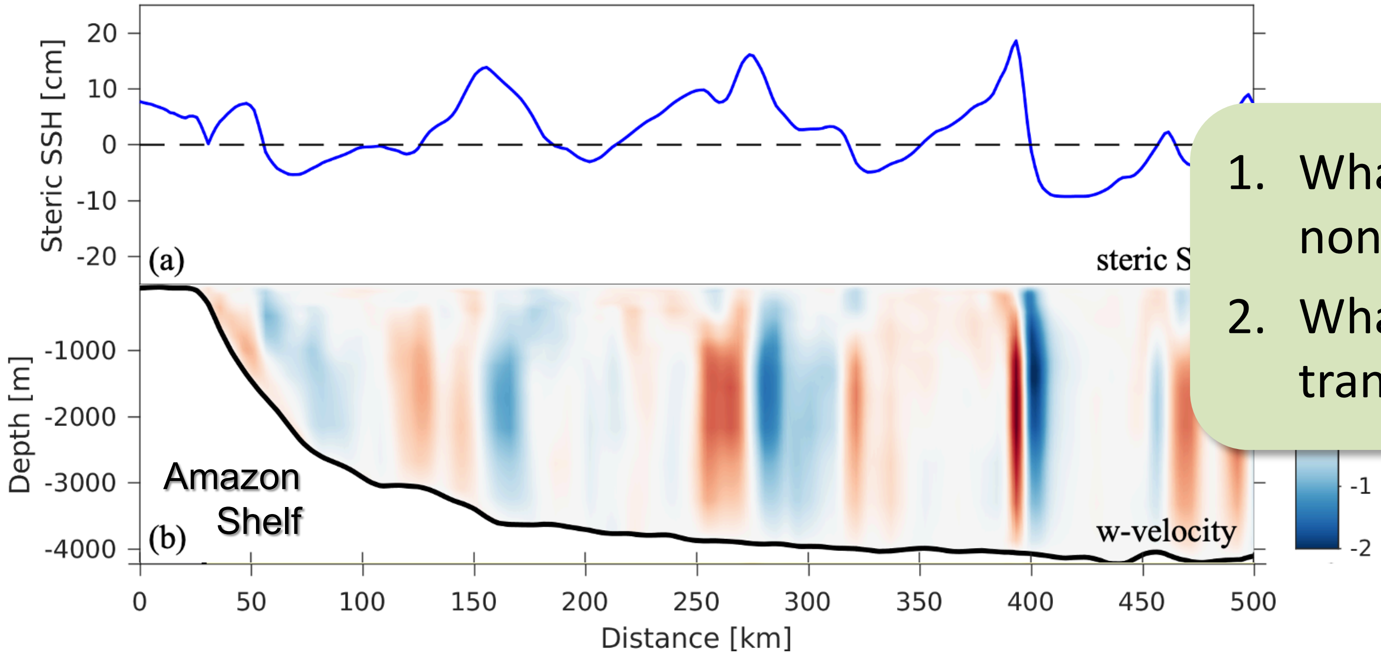
Nonlinear internal tides in a global HYCOM simulation



1. What is the spatial variability in nonlinear supertidal energy?
2. What are the mechanisms that transfer this energy?

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Methods

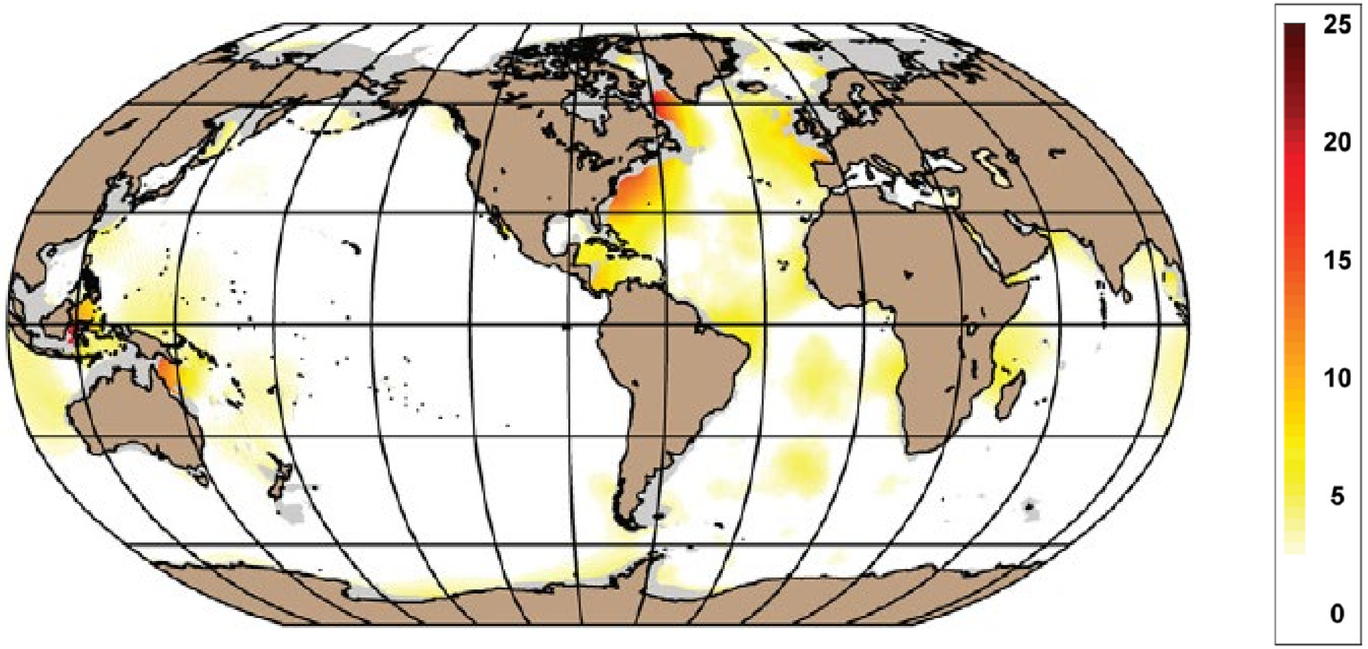
HYbrid Coordinate Ocean Model (HYCOM)

- Operational global ocean model of the U.S NAVY
- 1/25° (4 km) and 41 layers
- Atmospheric forcing: 3-hrly wind and solar radiation
- Tidal forcing: M_2, S_2, N_2, K_1, O_1 constituents
- M_2 RMSE with TPXO is 2.6 cm [Ngodock et al, 2016]

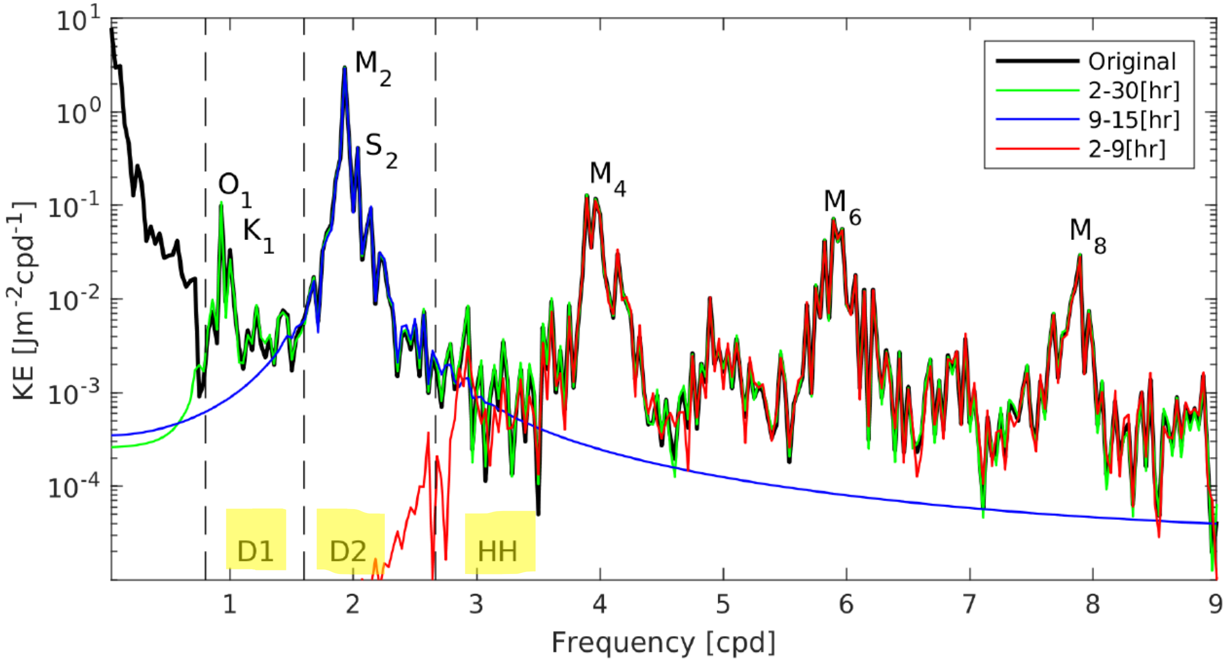
Diagnostics

- 30 days May/June 2019
- Bandpass hourly 3D fields into
  D1: Diurnal
  D2: Semidiurnal
  HH: Supertidal/higher harmonics, >2.67 cpd
- Compute time-mean tidal and supertidal internal wave energy terms:
  - kinetic energy KE
  - Energy flux $\mathbf{F}$

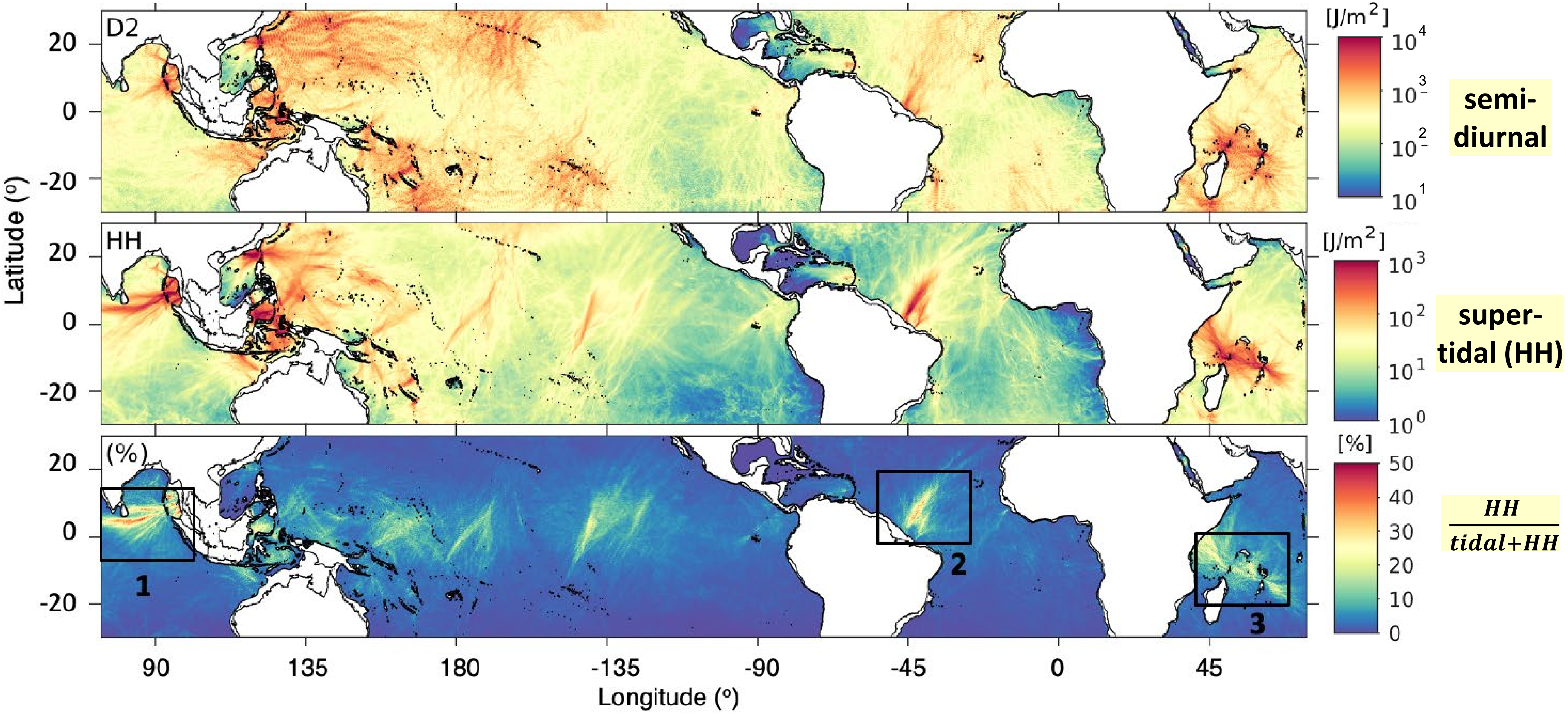
M_2 RMS error (cm) between HYCOM and TPXO8



Kinetic Energy spectrum off Amazon Shelf



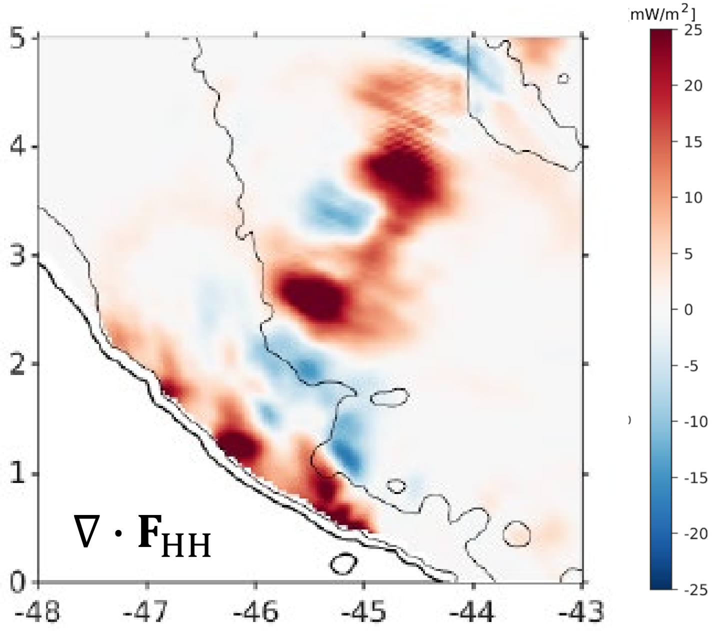
Tidal and supertidal (HH) Kinetic Energy

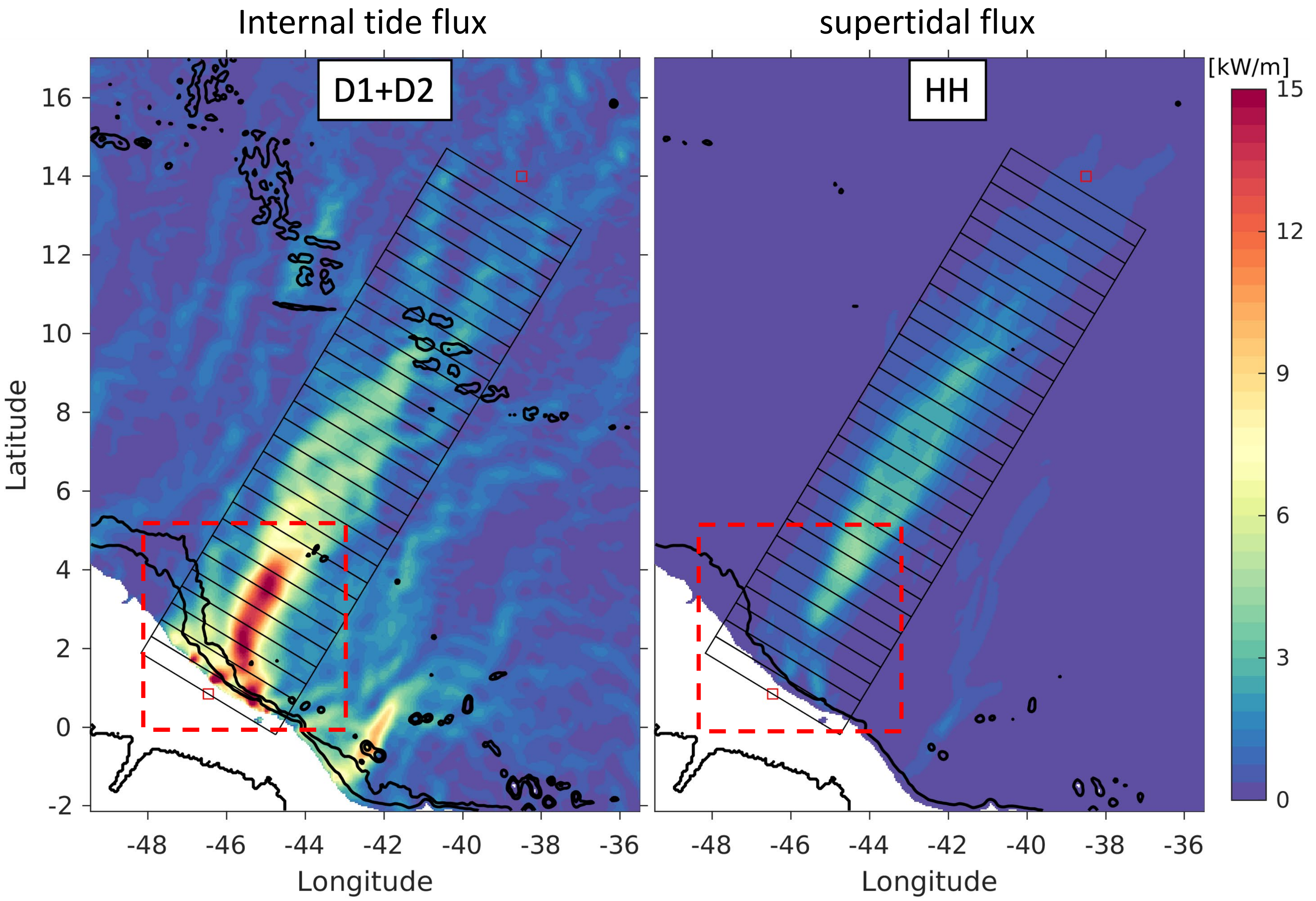


1) Bay of Bengal
2) Amazon
3) Mascarene

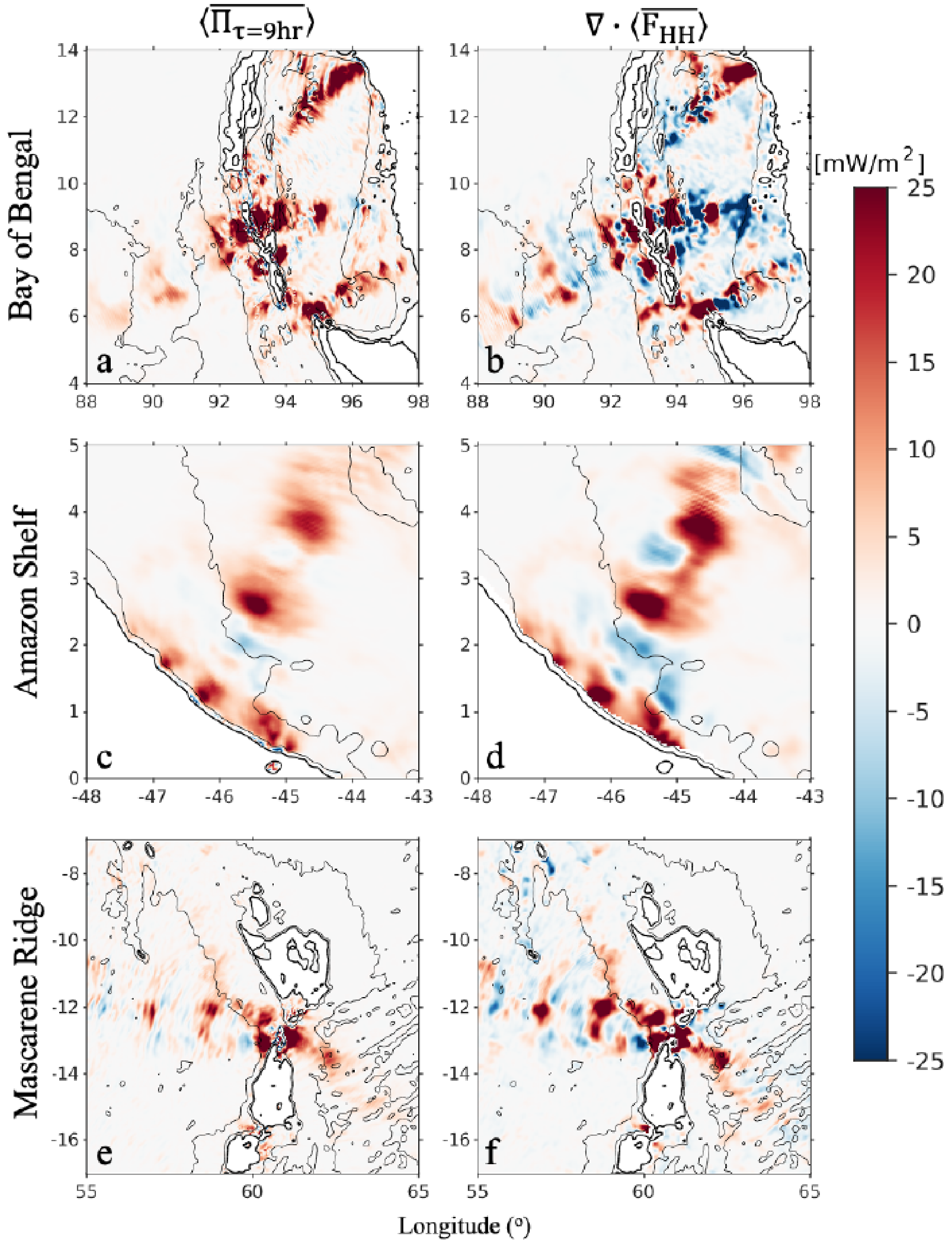
Energy fluxes near the Amazon shelf

- Off the shelf in deep water D1+D2 energy is transferred to supertidal energy (HH)
- This is clearly reflected in the supertidal flux divergence: $\nabla \cdot \mathbf{F}_{\mathrm{HH}}$





- The regular spaced patches of positive flux divergence are observed at other hotspots of nonlinear internal waves: **Bay of Bengal** and **Mascarene ridge**, among others
- Two questions arise:
  1. Can we explain the HH flux divergence with a term that considers the energy transfer from the D1+D2 to HH frequencies?
  2. What mechanism causes the regular spaced banding patterns of HH flux divergence?



1) Energy transfer term

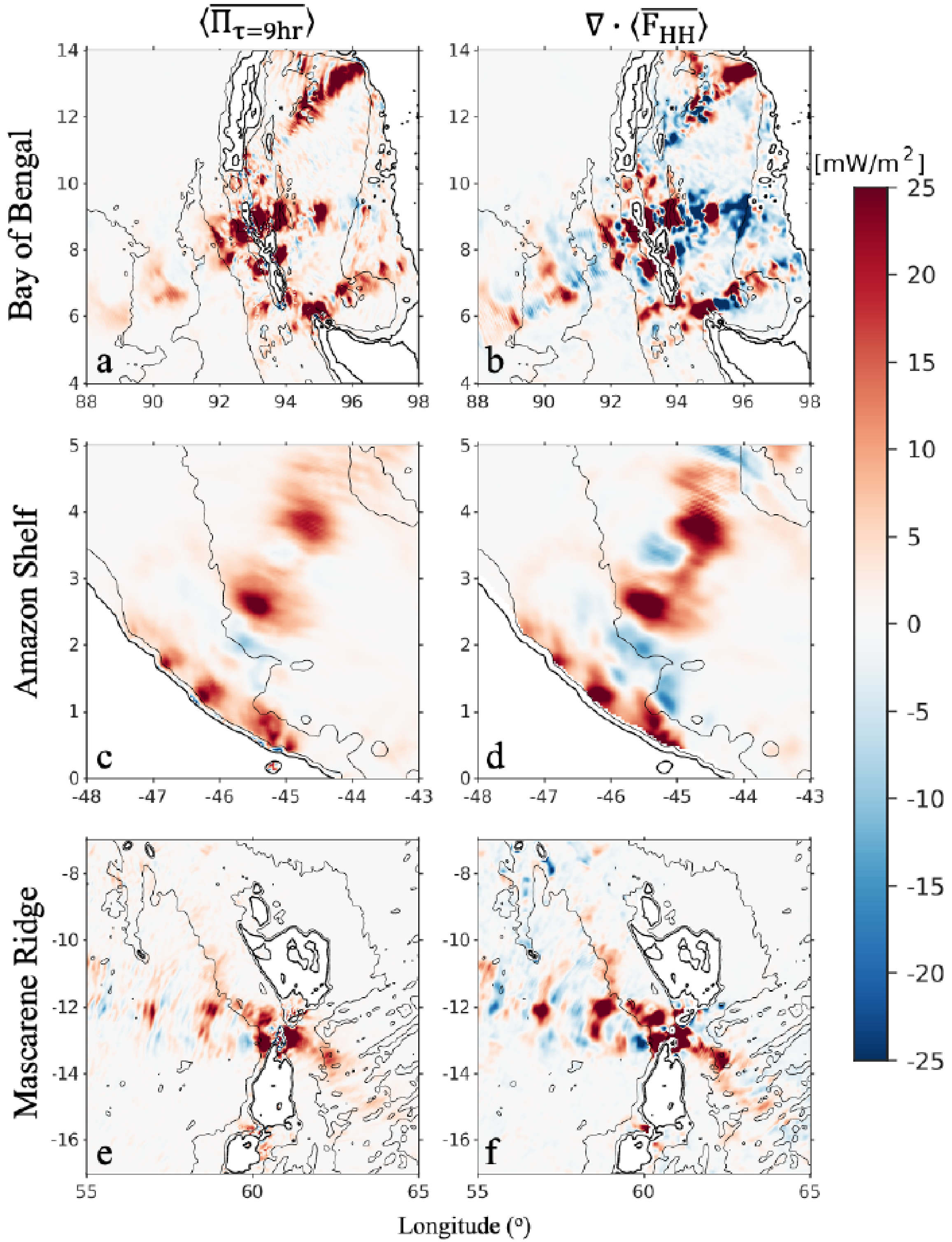
- The energy transfer to HH frequencies can be explained with coarse graining [Aluie et al., 2018; Barkan et al, 2021]

$$\Pi_\tau = -\rho_0\left(\widetilde{u_i u_j} - \widetilde{u_i}\widetilde{u_j}\right)\frac{\partial \widetilde{u_j}}{\partial x_j}$$

where $\widetilde{\ldots}$ is a 9-hour low-pass filter, and *i,j* are *x,y* or *z* coordinates

- The time-mean, depth-integrated HH energy balance looks like

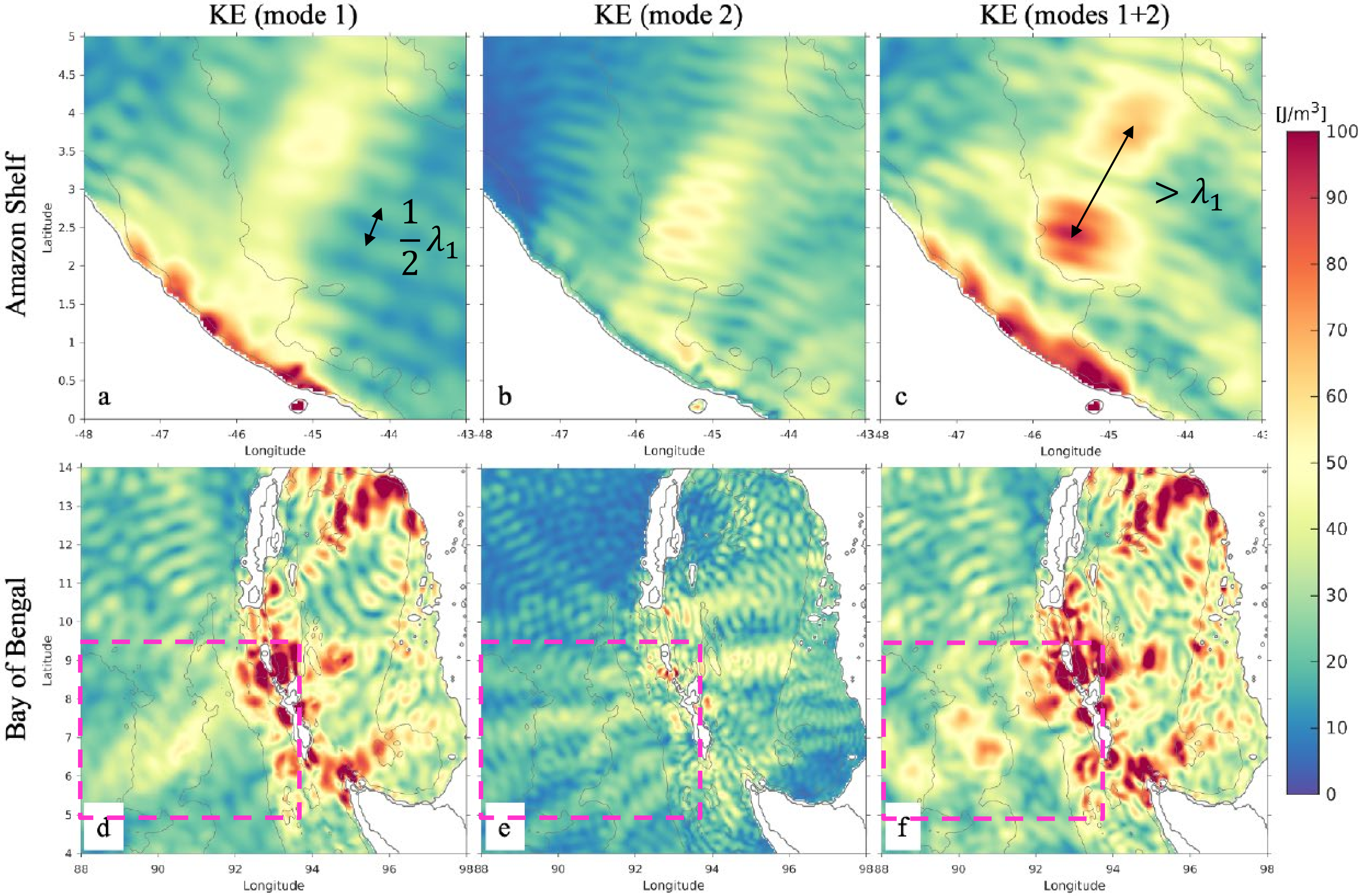
$$\langle\overline{\Pi_\tau}\rangle = \langle\overline{\nabla \cdot F_{HH}}\rangle + \mathcal{R}$$



2) Regular spaced banding patterns

- The distance between the patches is larger than mode-1 wavelength
- The patches are due to constructive interference between semidiurnal mode 1 and mode 2 waves
- Mode 1 overtake mode 2 waves generated at the shelf
- When mode 1 and 2 surface velocities superpose, surface KE and nonlinear energy transfers are enhanced

Surface KE



Surface intensified KE

- An internal wave velocity field can be decomposed into vertical modes:

$$u(z,t) = \sum_n \hat{u}_n(t)\Phi_n(z)$$

- At any given depth, kinetic energy for m1-2 is

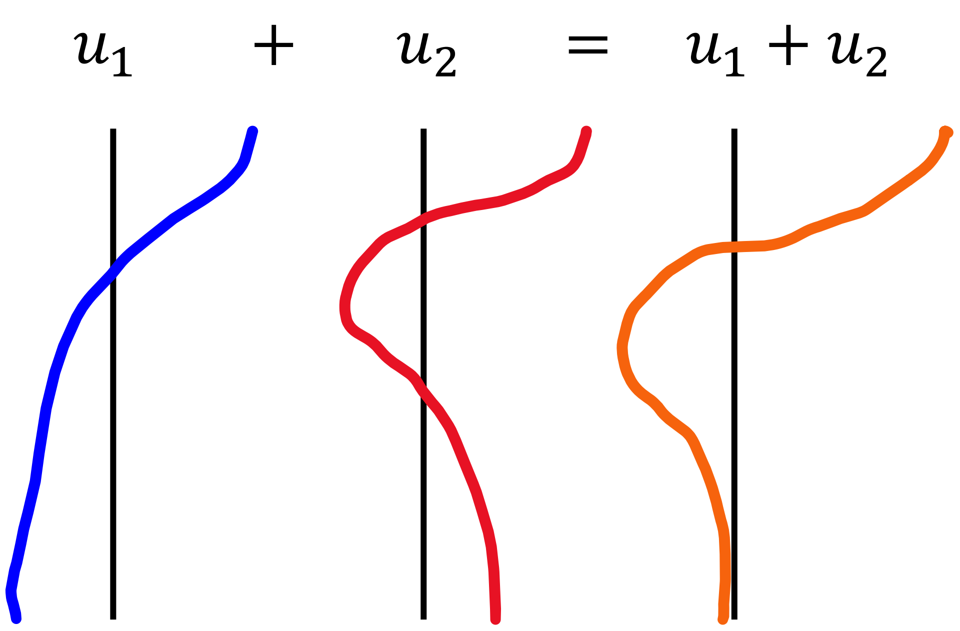
$$KE_{1+2}(z,t) = (\, \hat{u}_1(t)\Phi_1(z) + \hat{u}_2(t)\Phi_2(z)\,)^2$$

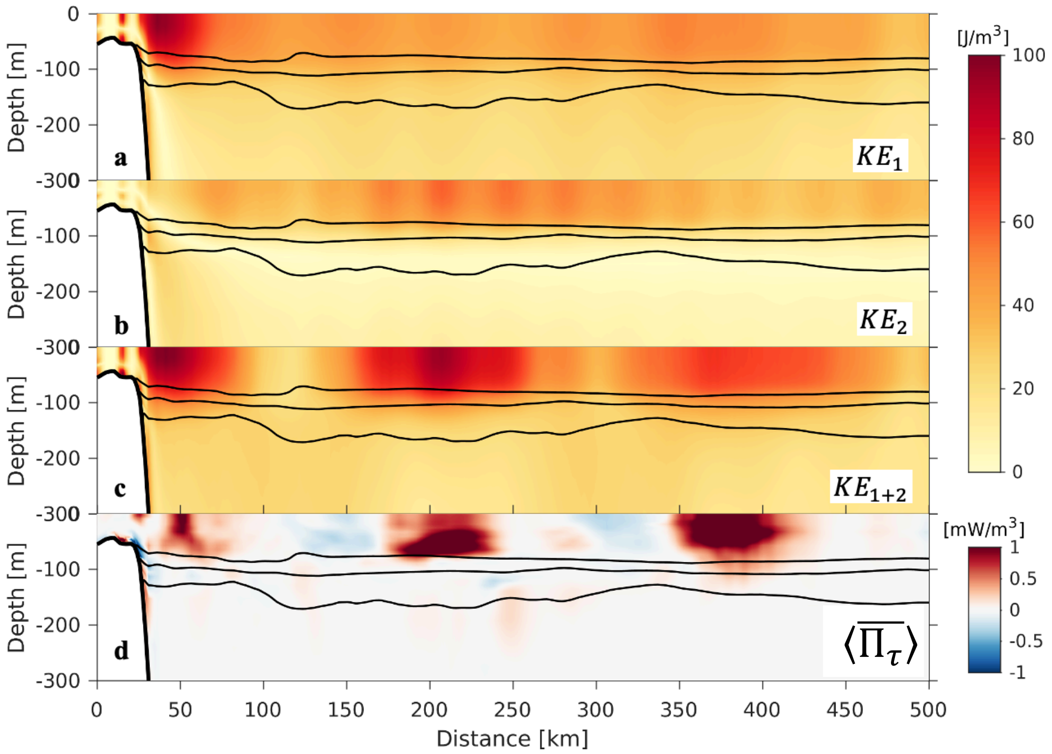
$$= \hat{u}_1^2\Phi_1^2 + \hat{u}_2^2\Phi_2^2 + 2\hat{u}_1\hat{u}_2\Phi_1\Phi_2$$

- When u_1 and u_2 are in phase at the surface, KE_{1+2} is enhanced

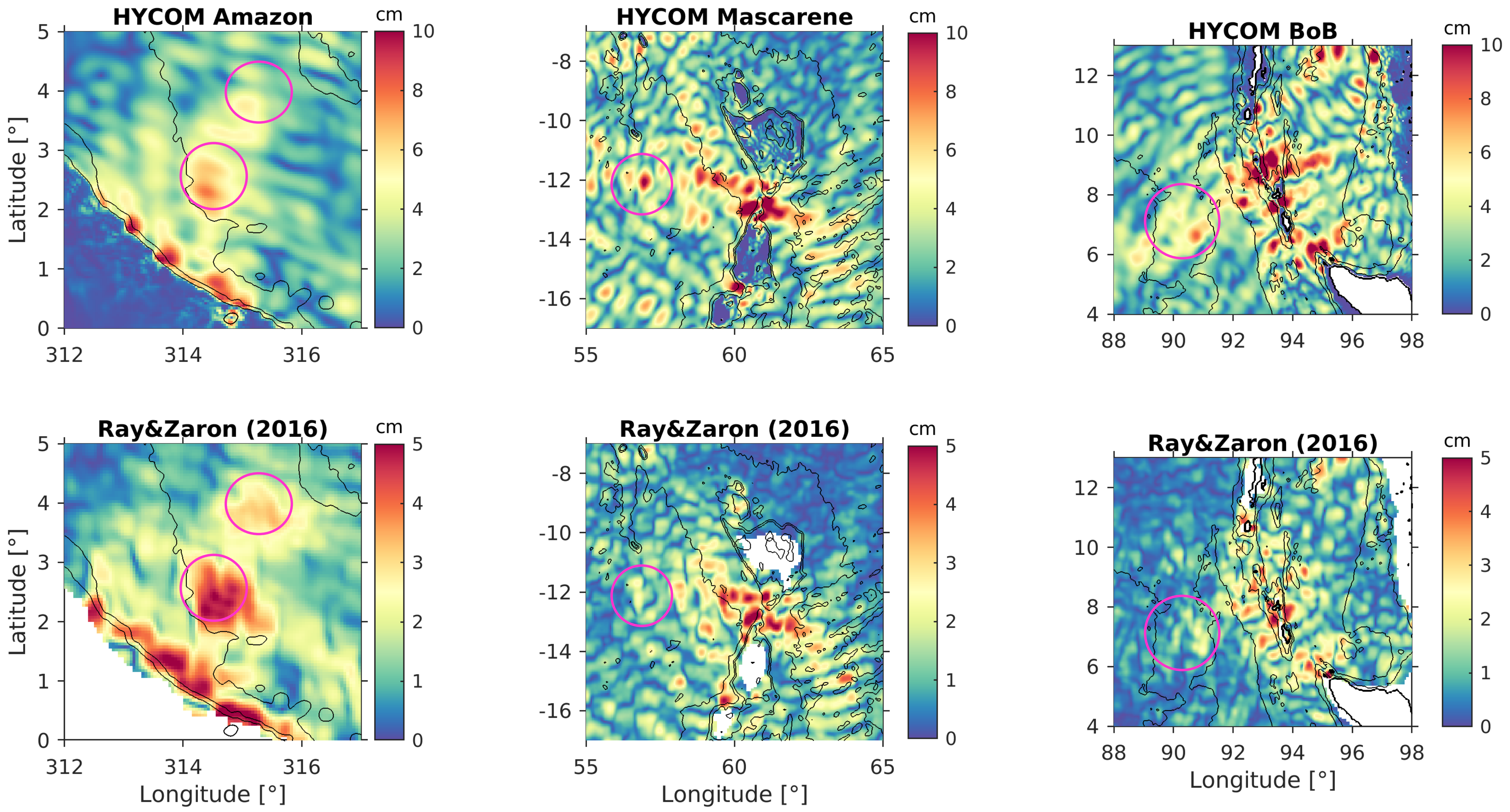
- Note, for the depth-integral, cross-term = 0 !!!

$$\int_{-h}^{0} KE_{1+2}(z,t)\,\mathrm{d}z = H(\hat{u}_1^2 + \hat{u}_2^2)$$





M_2 SSSH amplitude comparison with altimetry (Mujeeb Abdulfatai)



Conclusions

- In 4-km HYCOM simulations, supertidal energy is enhanced in the tropics
- This energy is NOT due to barotropic to baroclinic energy conversion at topography, but due to nonlinear energy transfers from the semidiurnal internal tide
- These energy transfers are estimated with a coarse graining energy flux $\langle\overline{\Pi_\tau}\rangle$
- $\langle\overline{\Pi_\tau}\rangle$ is enhanced when semidiurnal mode 1 and 2 velocities superpose near the surface, creating the banding patterns
- The banding patterns are also observed in altimetry and other model simulations

- These supertidal energy transfers have been ignored as a decay mechanism for the low-mode internal tides
- In the tropics, area-integrated $\langle\overline{\Pi_\tau}\rangle \approx 45$ GW, which is comparable to PSI (≈ 40 GW; Ansong et al., 2018)