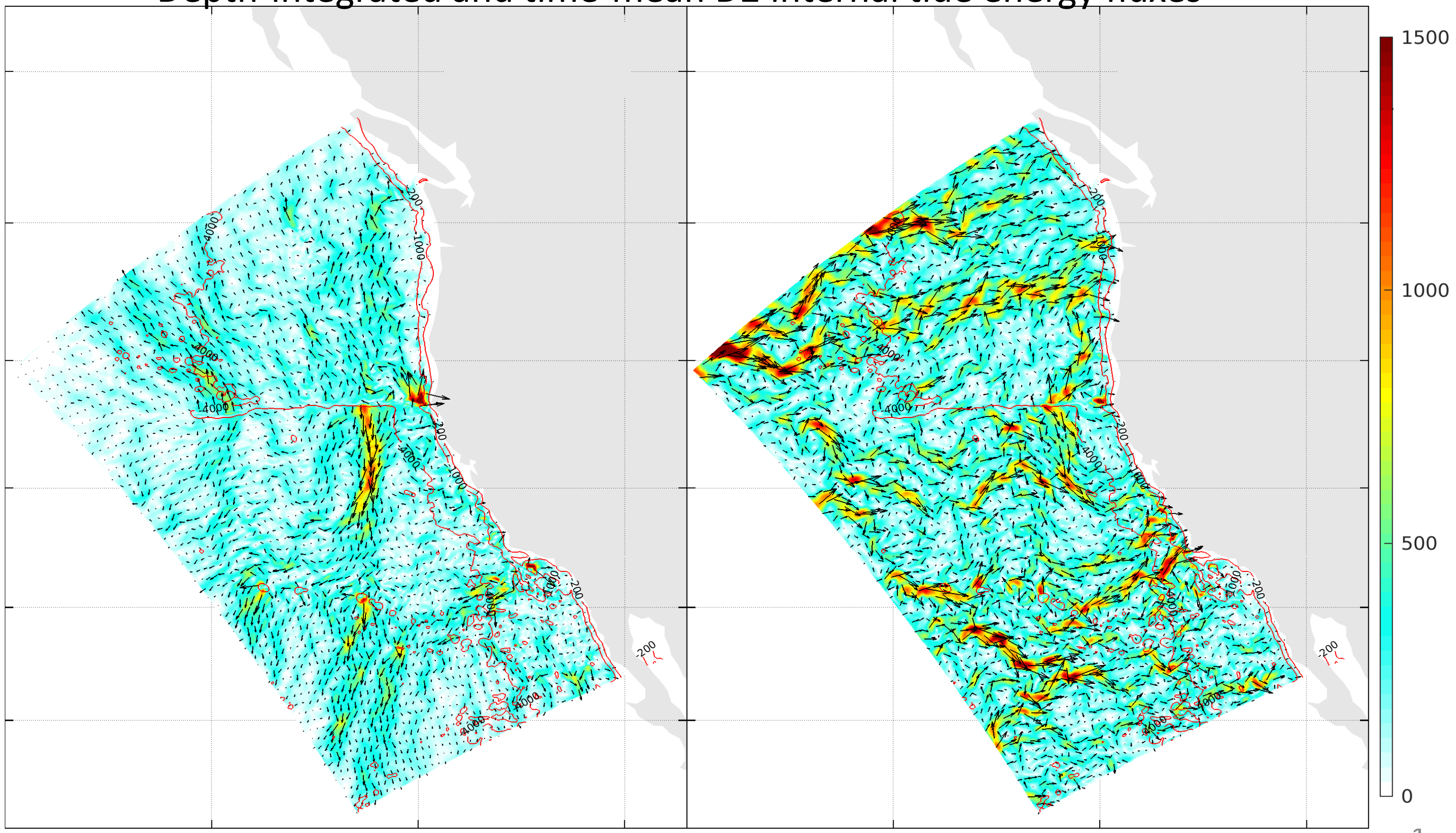
Remote Internal Wave Forcing of Regional Ocean Simulations Near the US West Coast (USWC)

Oladeji Siyanbola, Maarten Buijsman, Audrey Delpech, Roy Barkan, Jay Shriver and Brian Arbic

Depth-integrated and time-mean D2 internal tide energy fluxes



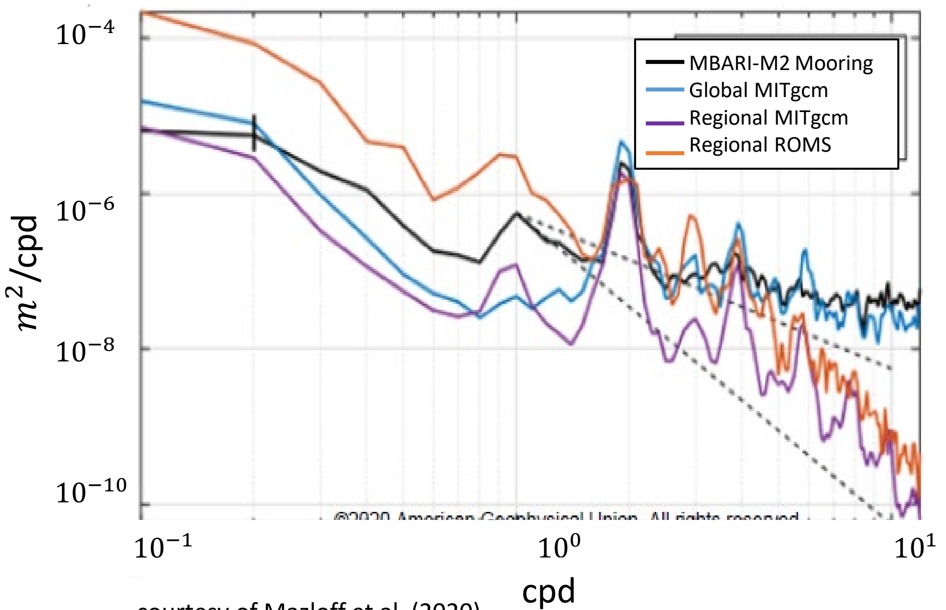
- Without remote internal wave forcing
- With remote internal wave forcing

MOTIVATION

- Regional models underestimate internal wave energetics if remote internal waves are excluded (e.g., Buijsman et al., 2012, Kumar et al., 2018, Mazloff et al., 2020, Nelson et al., 2020)

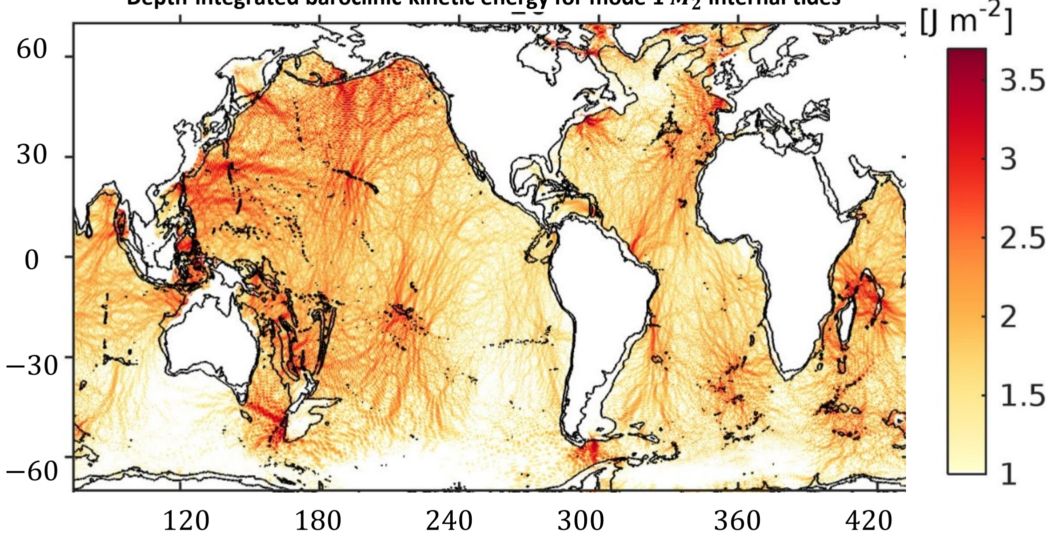
- ~31% of remote internal waves energy is lost on the continental margins (Waterhouse et al., 2014)

Frequency spectra for regional models (MITgcm and ROMS), global MITgcm and mooring.



courtesy of Mazloff et al. (2020)

Depth-integrated baroclinic kinetic energy for mode 1 M_2 internal tides



courtesy of Buijsman et al., 2020

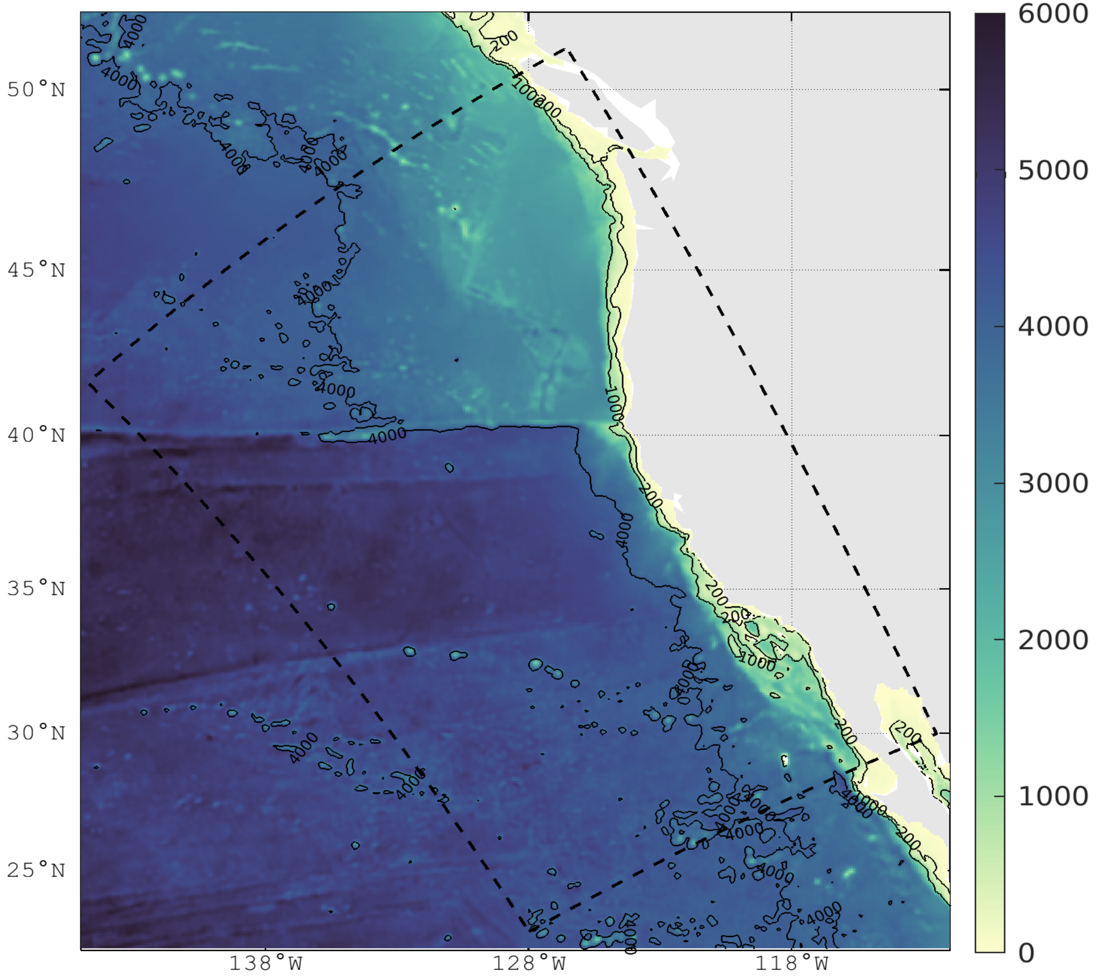
RESEARCH QUESTIONS

- How well do Orlanski and specified OBCs in combination with sponge layers perform with high-freq. baroclinic forcing on the boundaries?
- How much do model-data comparisons in the California Current System improve with remote high freq. baroclinic forcing?
- Does internal tide dissipation increase on the continental margin with remote internal wave forcing?

METHODS

- Regional Ocean Modeling System (ROMS)
  - 11 trial simulations of the USWC
  - Hor. Res.: 4 km, 437 x 662 rho-points
  - Ver. Res.: 60 layers, θ_S = 6, θ_b = 3 and h_c = 250 m.
- Types of boundary conditions
  - Barotropic mode: Specified and Flather OBCs
  - Baroclinic mode: Specified and Orlanski OBCs
- Barotropic-baroclinic boundary condition combinations:
  - Specified-Specified (SS),
  - Flather-Orlanski (FO)
  - Flather-Specified (FS).
- Lateral Open Boundary Forcing
  - Low frequency: ROMS 12 km (Renault et al. (2021))
  - High frequency: HYCOM 8km expt_06.1 (Buijsman et al. (2017, 2020)
cutoff period= 36 hours
- Atmospheric forcing: Weather Research and Forecast (WRF) model

Sea floor depth (m)



ESTIMATION OF REFLECTED FLUX:

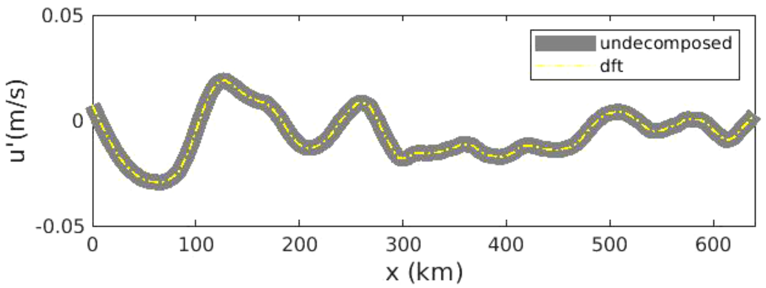
- We consider the baroclinic energy budget for the sponge layer

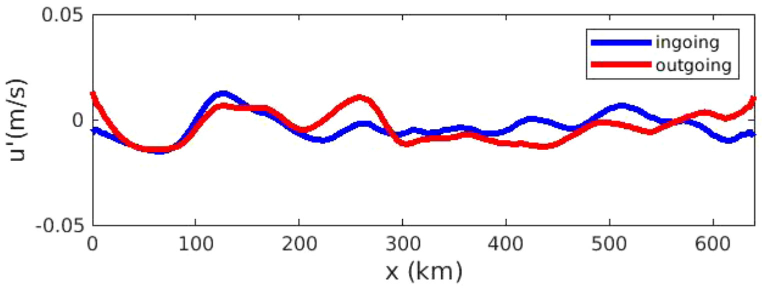
$$F_r = F_{out} - F_{HYCOM} - F_{con}$$

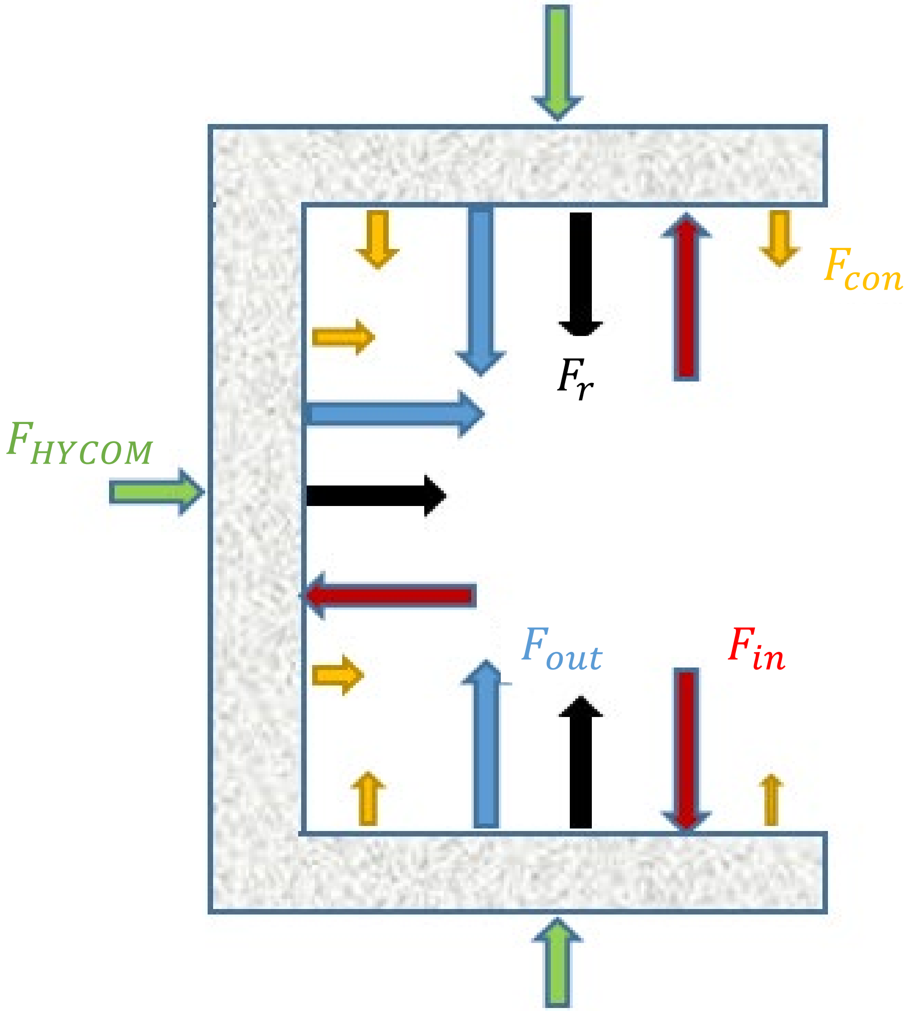
- Discrete Fourier Transform to compute F_{HYCOM}, F_{IN} & F_{OUT}
- Uncertainty in reflected flux computation

$$F_{r,1} \leq F_r \leq F_{r,4}$$

- Reflection coefficient, λ = $\frac{F_r}{F_{in}}$



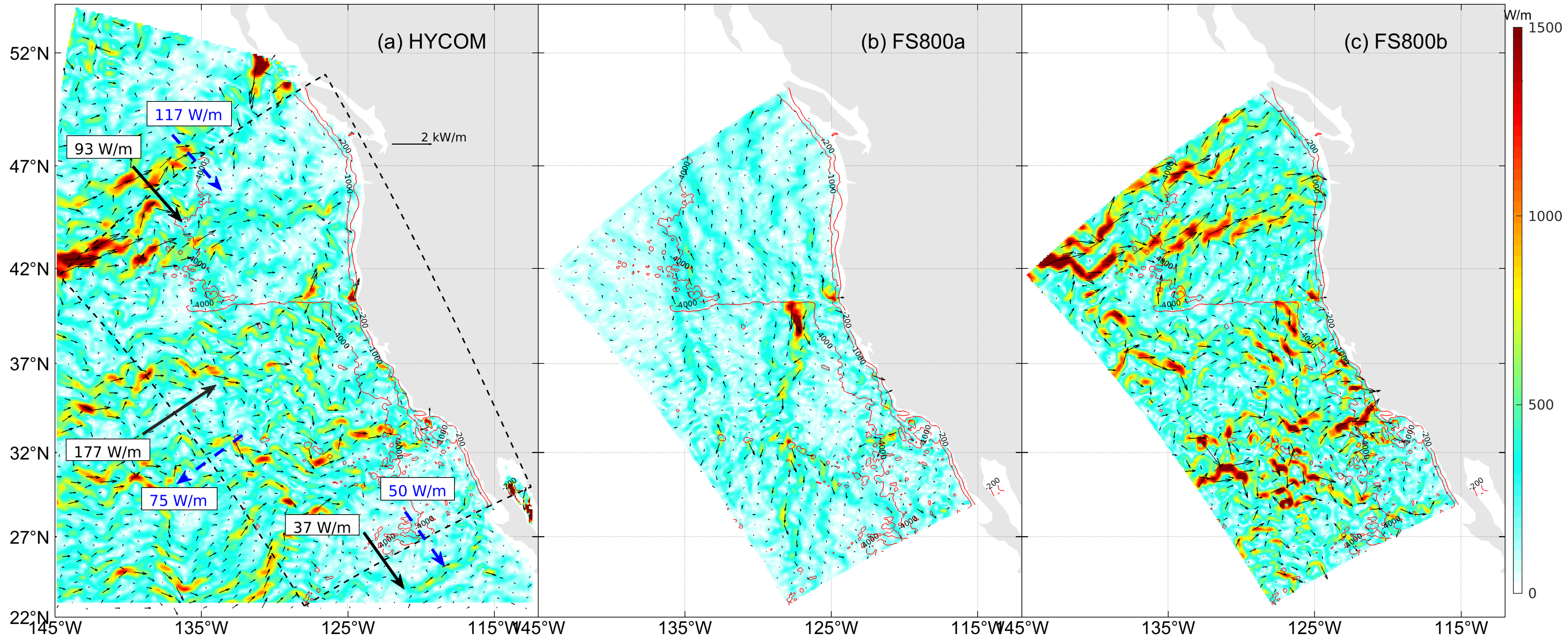




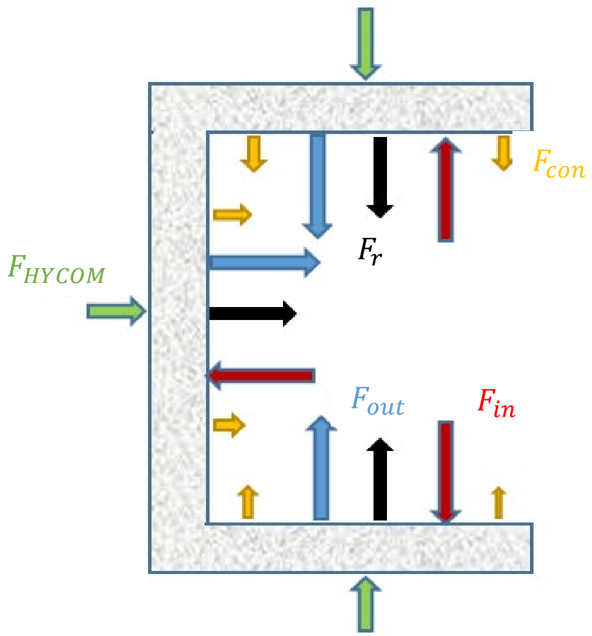
- F_{HYCOM}: unidirectional incoming flux from HYCOM
- F_{IN} & F_{OUT}: unidirectional ingoing and outgoing flux, respectively
- F_{con}: Barotropic-to-baroclinic tide conversion
- $F_{out} > F_{HYCOM} + F_{con}$ → Reflection

RESULTS

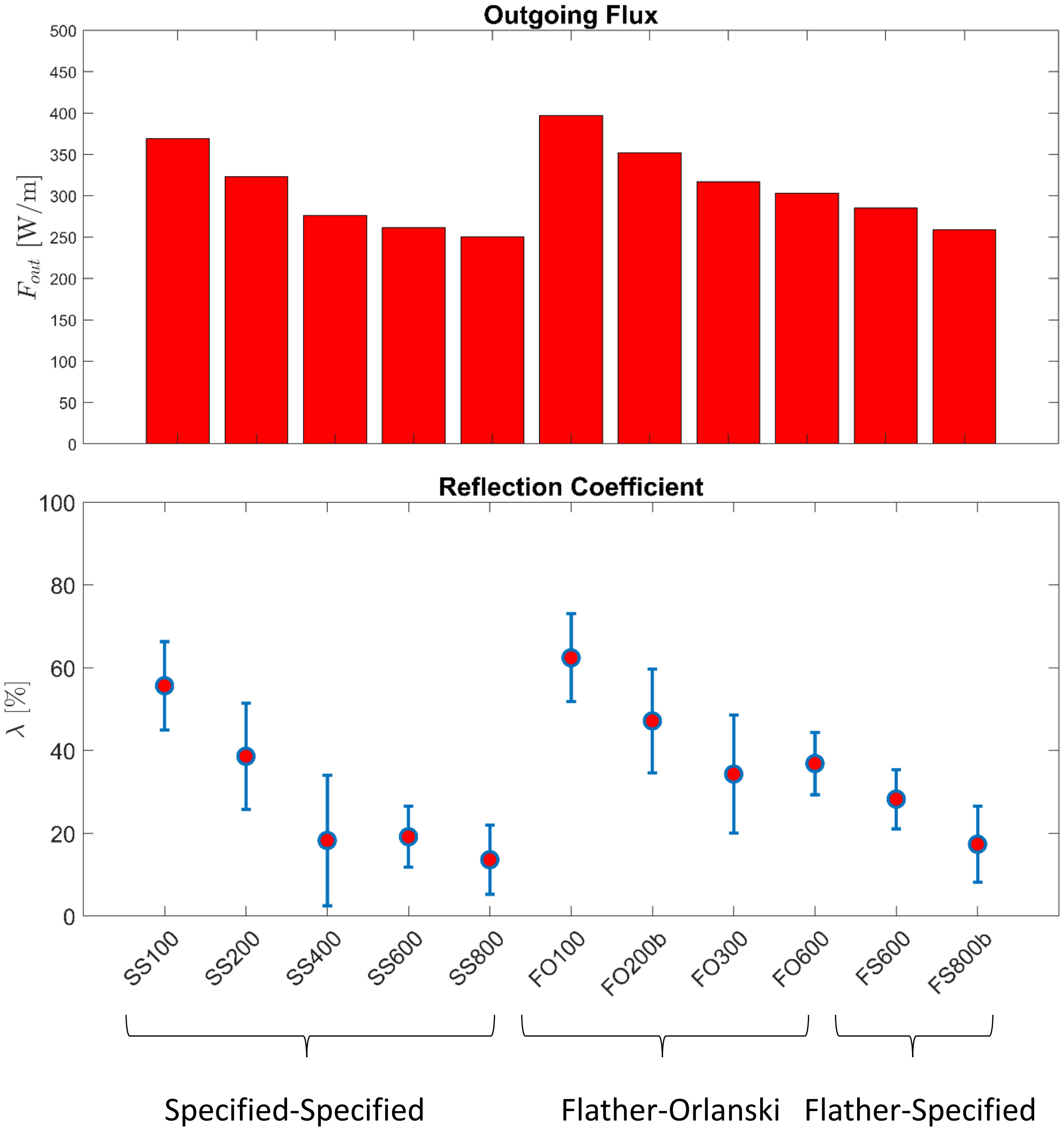
D2 Depth-integrated and time mean (01, July – 31 August, 2012) energy fluxes



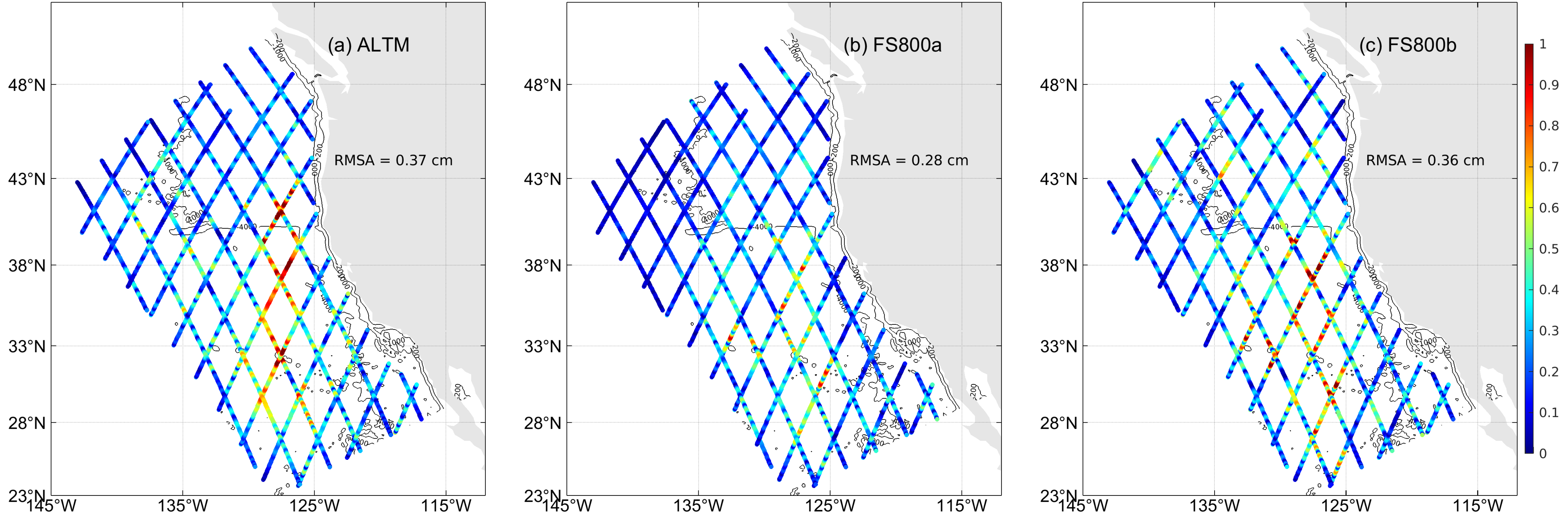
- Increased internal tide energy with remote high-freq. baroclinic forcing
- Net Remote Internal Wave Flux at the open boundaries – 541 MW (93 W/m)
- NIWs > 50% of net fluxes at Northern and Southern boundaries



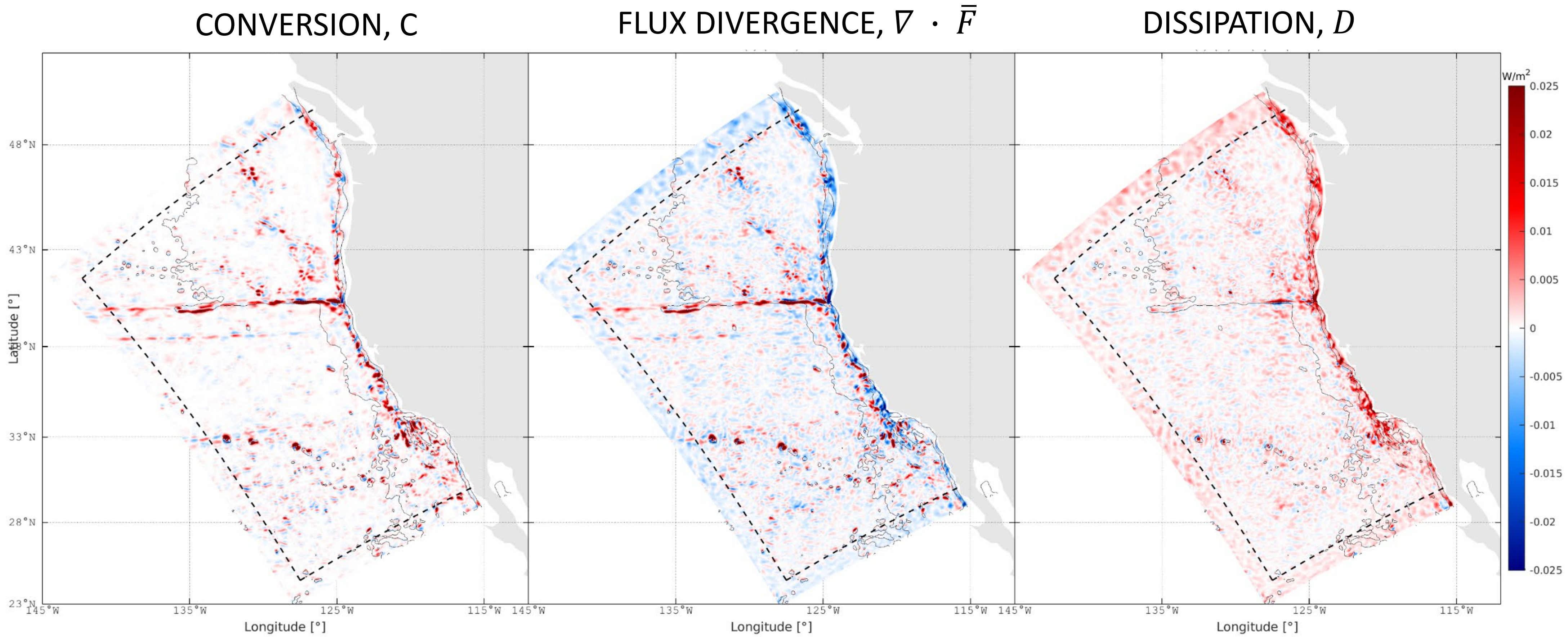
- $F_{out} > F_{HYCOM} + F_{con}$ → Reflection
- Reduction in F_{out} and λ (≤ 73%) with increase in sponge viscosity and width
- Lowest reflections for the SS simulations
- Stronger reflections for Orlanski OBC compared to Specified OBC
- Best trial simulation is FS800b



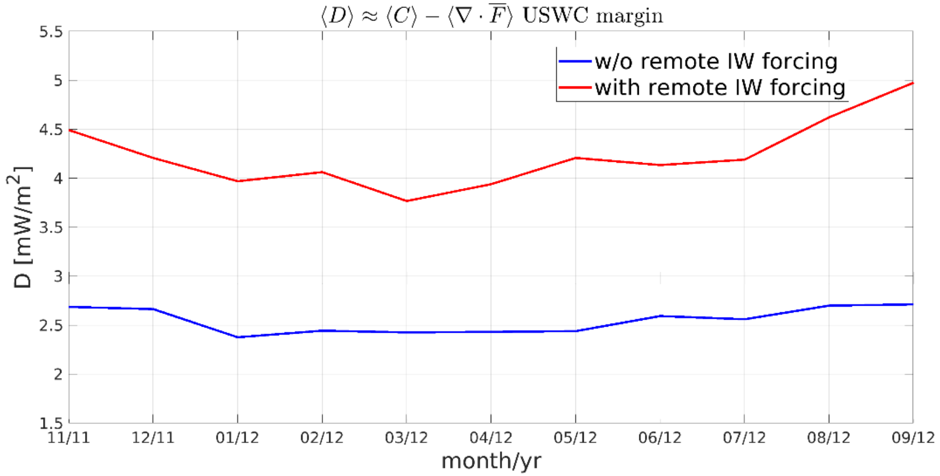
VALIDATION: Altimetry



- RMSA in FS800b, with remote internal wave forcing, has increased by 29% as compared to RMSA of FS800a
- The spatial correlation of FS800b with altimetry has increased by 35% relative to FS800a
- FS800b has R^2 = 95% when compared to altimetry



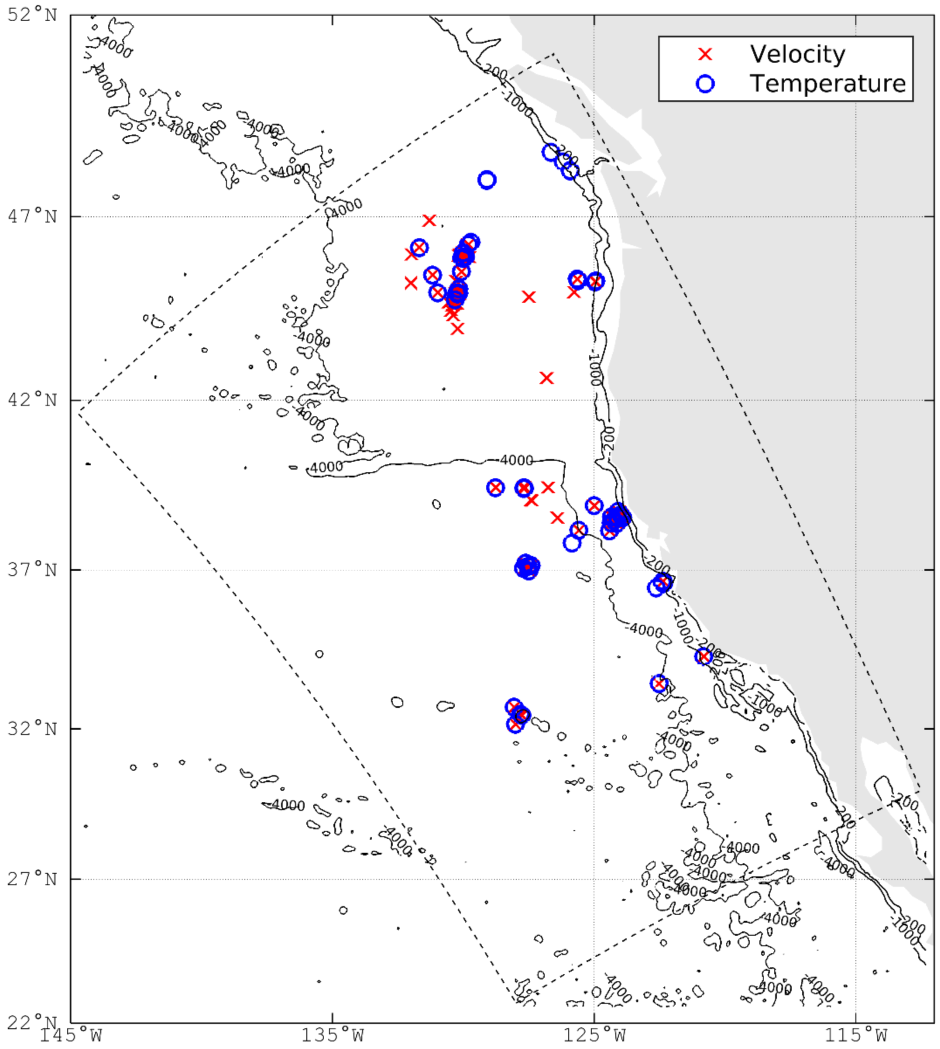
- $D \approx C - \nabla \cdot \bar{F}$
- Highly dissipative: Coastal and sponge regions
- 55-83% increase in dissipation on the continental margin with remote IW forcing
- The addition of remote internal waves increases the seasonal variability in the dissipation

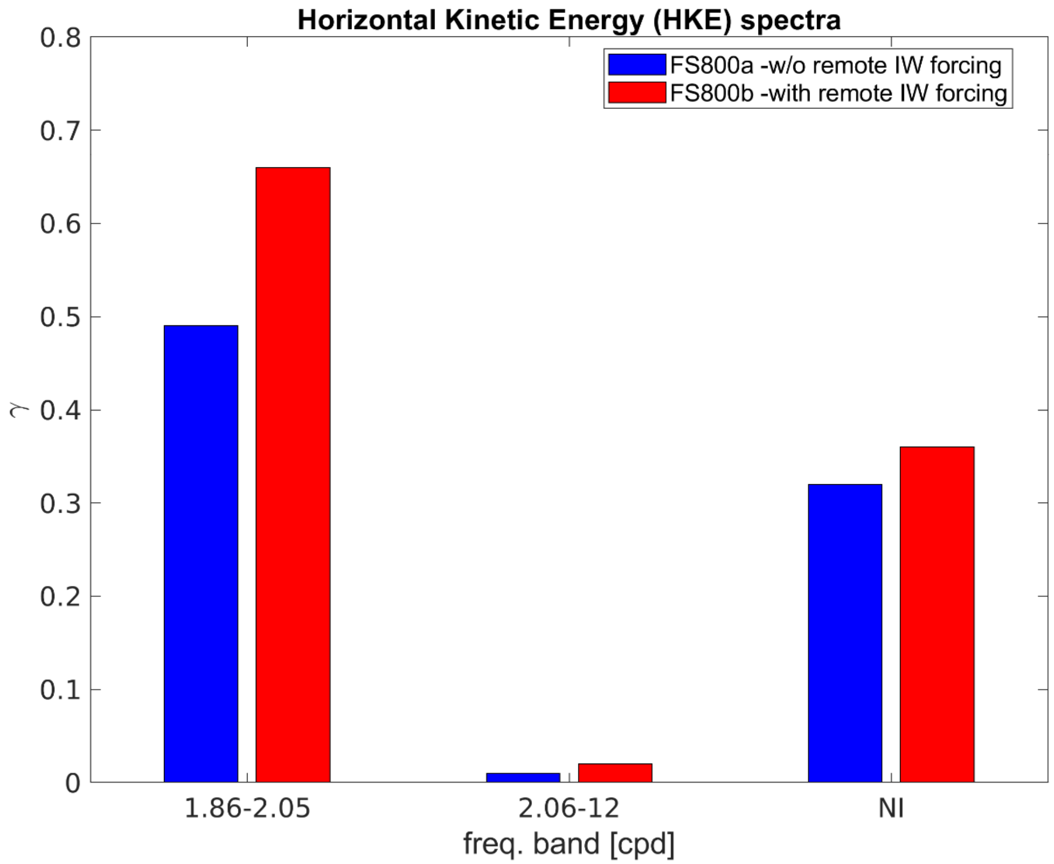


- CONCLUSIONS
  - Best OBC combination (Barotropic-Baroclinic): Flather-Specified
  - Sponge layers are necessary buffer zones for reflection mitigation
  - Increase in model-data agreement with remote high-frequency baroclinic forcing.
  - Increase in internal tide dissipation on the USWC continental margin with remote internal wave forcing

- FUTURE RESEARCH
  - Fate of remote internal waves on the USWC continental margin
  - Impact of remote internal wave forcings on mixing on the USWC continental margin

VALIDATION: Moorings



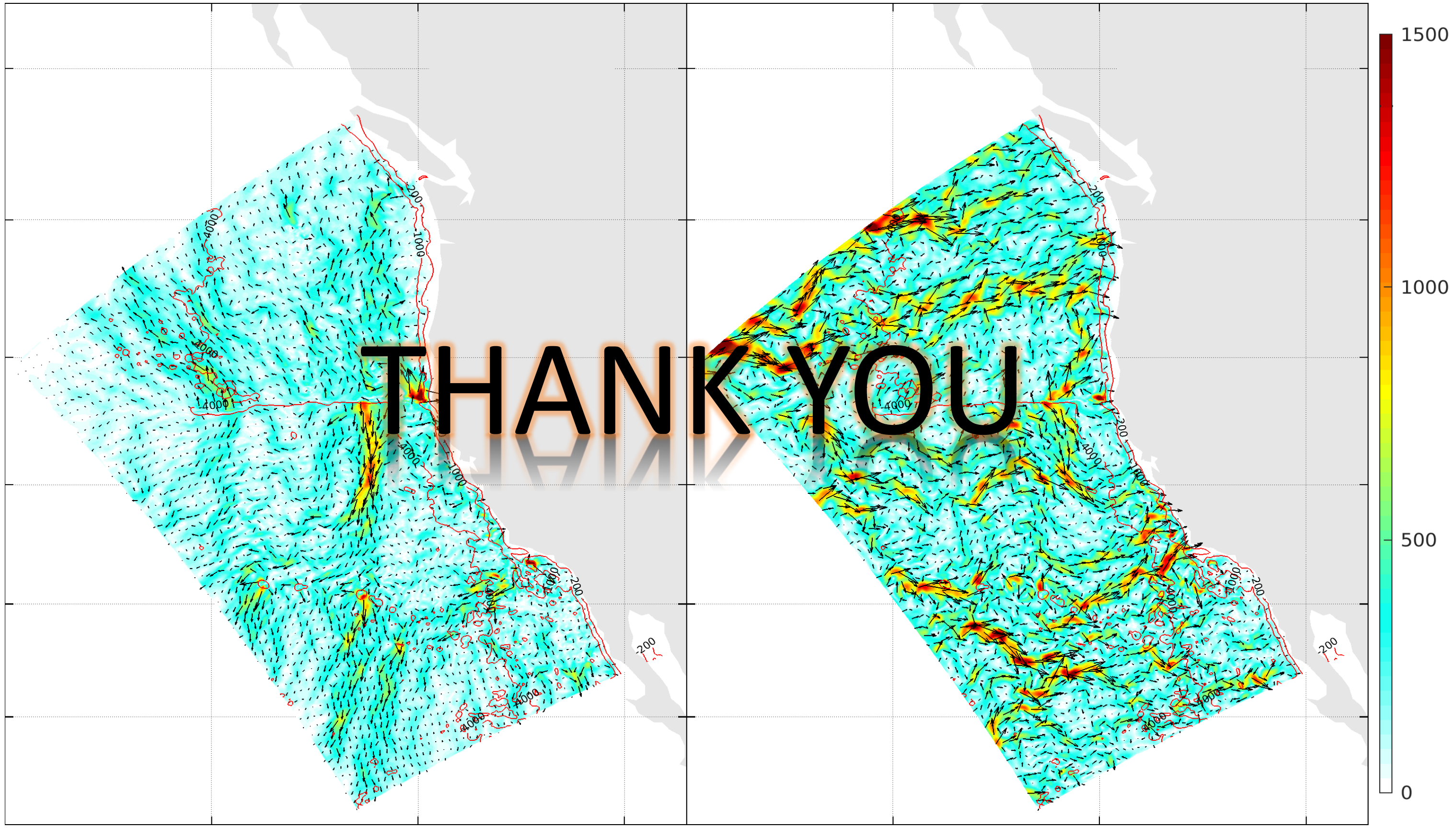


$$\gamma = \frac{Variance_{ROMS}}{Variance_{obs}}$$

(Luecke et al., 2020)

- Increase in model variance across all high frequency bands for both KE and temp. spectra with remote internal wave forcing.

Depth-integrated and time-mean D2 internal tide pressure fluxes



- **Without remote internal wave forcing**
- **With remote internal wave forcing**