Comparison of internal gravity wave spectra in high-resolution global simulations with observations

USING: Realistic HYCOM and MITgcm Simulations

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Background: Relevance to altimetry

- Internal tides and the internal gravity wave (IGW) continuum are an important, but temporally aliased, signal in altimetry data.
- Examination of small-scale eddy dynamics in high-resolution altimetry missions requires accurate prediction and removal of internal tides and the IGW continuum.
- Coherent internal tides will be challenging.
- Incoherent internal tides, and the IGW continuum, will be even more challenging.

Background: Global internal tide and IGW continuum modeling

- **Classical paradigm of IGW continuum**
  - Fluctuating winds drive near-inertial waves
  - Barotropic flow over rough topography yields internal tides (e.g., Ray and Mitchum 1996, 1997)
  - Nonlinear interactions fill out the IGW continuum spectrum, i.e. the Garrett-Munk spectrum
- →Global modeling of IGW continuum requires high-frequency wind forcing, tidal forcing, and high resolution (to allow nonlinear interactions)
- Background stratification→ need low-frequency winds, buoyancy forcing, and mixing.

Background/history: Global internal tide and IGW continuum modeling

Global hydrodynamical tide modeling

Hydrodynamical barotropic tide models

- Pioneering work in 1970s by Hendershott and others
- Assimilative hydrodynamical models for altimeter corrections: FES. TPXO, Kantha model

First global baroclinic tide models

- Hallberg isopycnal Model (Arbic et al. 2004, Simmons et al. 2004)
- No atmospheric forcing
- Simplified stratification

Global atmospherically forced models

Early work

- QG basin models of Holland
- Realistic-domain models at ~1/4 to 1/6 degree: Semtner and Chervin, POP team
- North Atlantic ~1/10°: Paiva et al. (1999), Smith et al. (2000)

Global eddying models

- Global ~1/10° or better simulations:

POP: Maltrud and McClean (2005)
NLOM: Shriver et al. (2007)
HYCOM: Chassignet et al. (2009)
Mercator group

Global high-resolution models with simultaneous atmospheric and tidal forcing

Carry barotropic tides, internal tides, eddying general circulation all at once

- First done in 1/12.5° HYCOM (Arbic et al. 2010)
- Other groups have followed suit (STORMTIDE, MITgcm,French and UK efforts)

"HYCOM simulations continue to evolve: wave drag tuning, many comparisons to observations, horizontal resolution increased to 1/25°, data-assimilative machinery for eddies, Kalman Filter to improve tidal accuracy

Background/history: Global internal tide and IGW continuum modeling

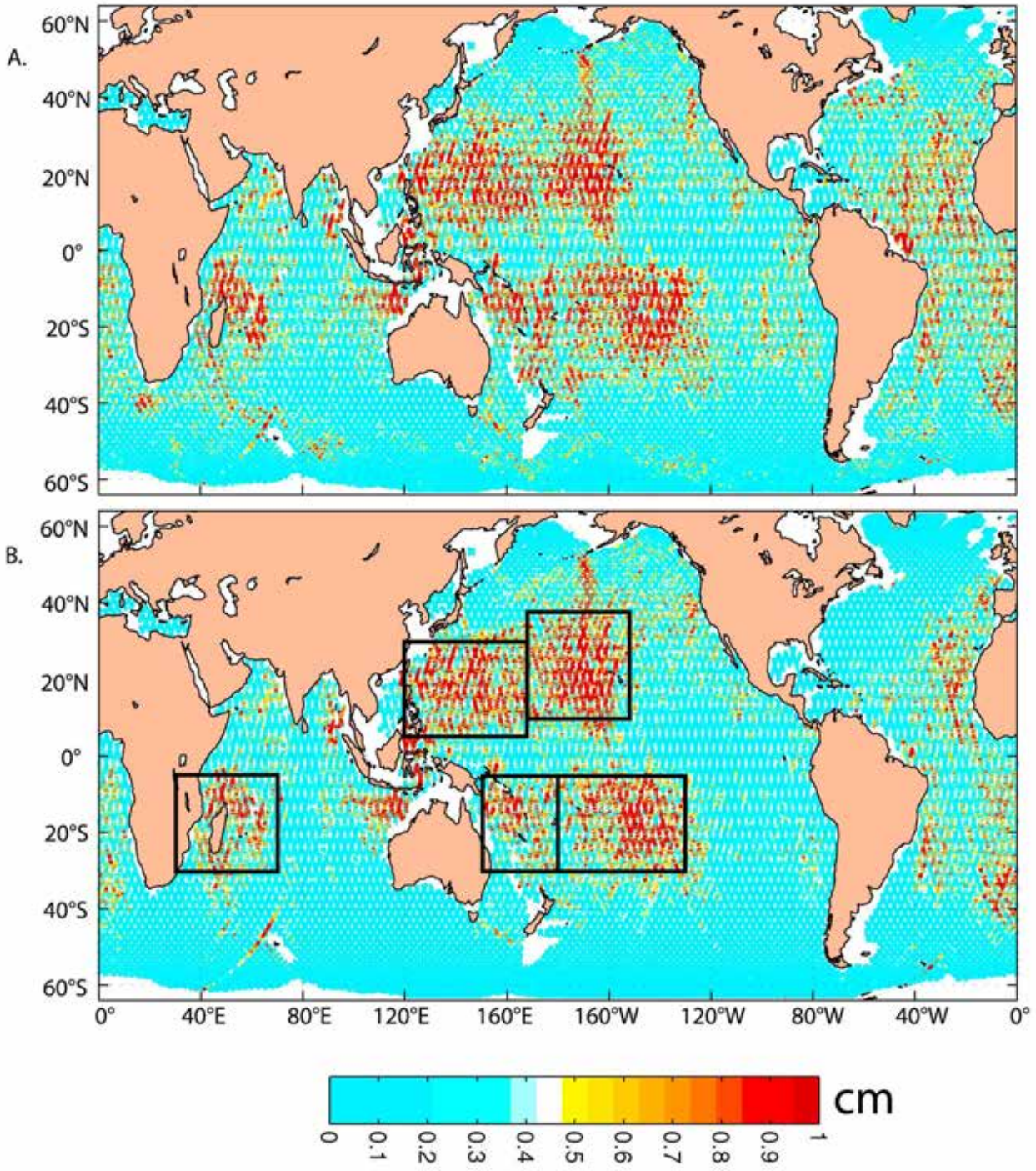
- **IGW continuum spectrum in models**

- Müller et al. (2015): HYCOM has a partial IGW continuum.
- Opens a new door.

- **MITgcm simulation**

- Also has a partial IGW continuum (Rocha et al. 2016a, 2016b)
- Led by Dimitris Menemenlis
- Contributions from Ayan Chaudhuri, Bob Ciatti, Christopher Henze, Chris Hill, Bron Nelson, and Rui Ponte
- Includes tidal and atmospheric forcing
- Largest ocean simulation done to date.
  - Higher horizontal and vertical resolution than HYCOM→matters a lot for IGW continuum
- Examined at Scripps, JPL, U-Michigan, U-Hawaii (Rocha et al. 2016a, 2016b, Savage et al. 2017b, Wang et al. in review, Qiu et al. in review).

Coherent internal tides



M_2 coherent internal tide SSH amplitude

Determined by high-passing amplitudes of total M_2 SSH (as in Ray and Mitchum 1996)

←Along-track altimeter data

←HYCOM patterns are grossly similar; noticeable differences in Atlantic

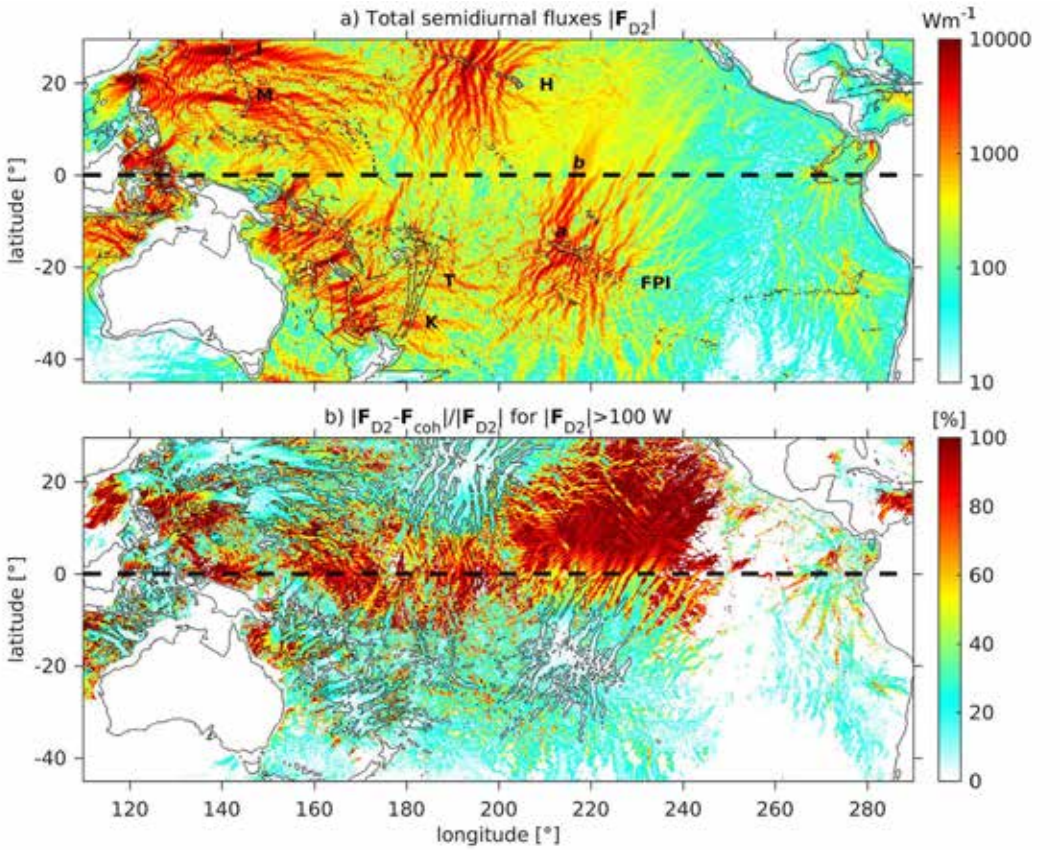
NOTE “dead spot” in equatorial Pacific in both plots

Shriver et al. (2012)

Incoherent internal tides

- Examined in many regional models (e.g. Zaron and Egbert 2014)
- Examined in global HYCOM in Shriver et al. (2014), Ansong et al. (2017), Buijsman et al. (2017)

Near-equatorial Pacific semidiurnal energy fluxes in HYCOM



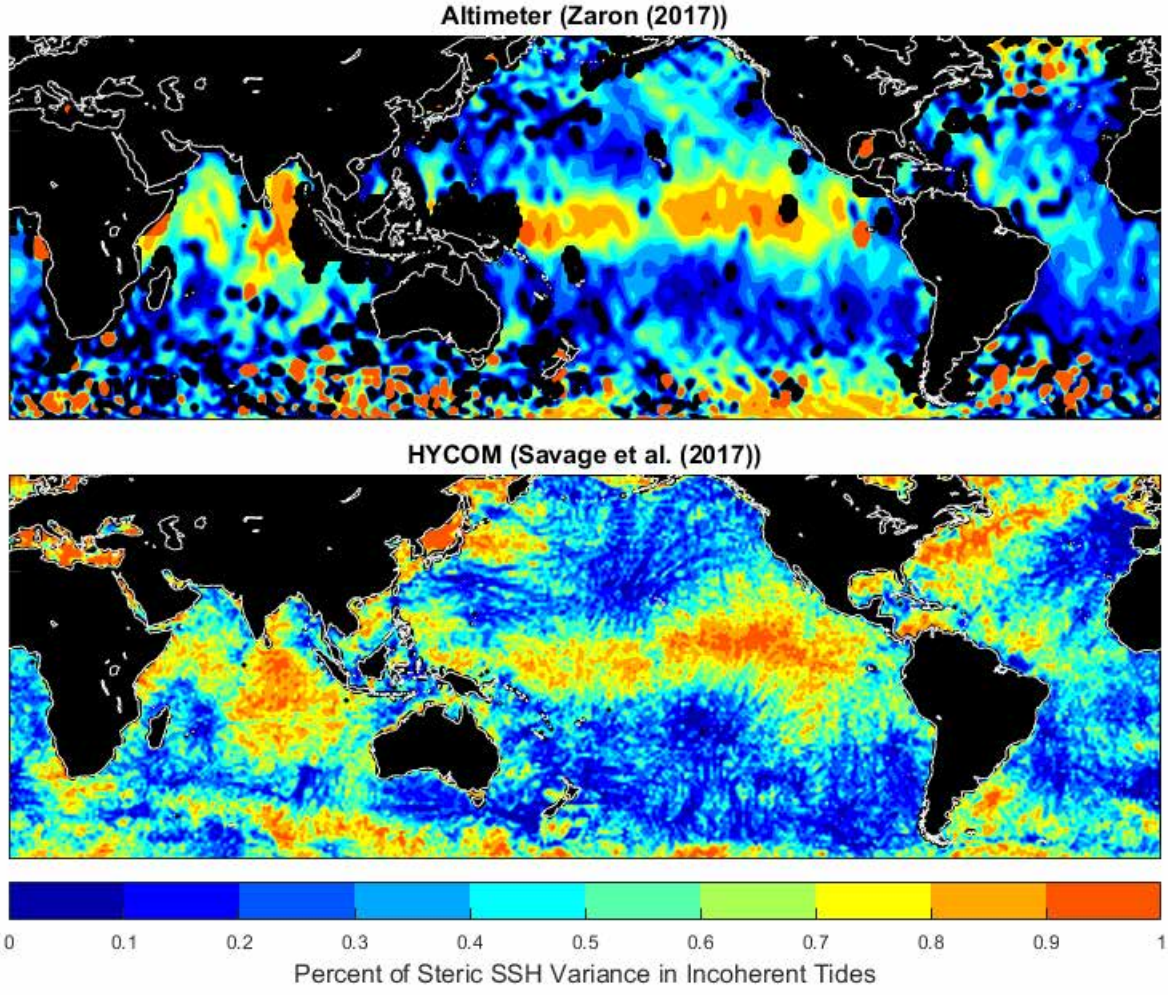
←Semidiurnal band fluxes radiating from the French Polynesian islands cross the equator.

←But ratio of incoherent/total flux increases greatly as one crosses the equator.

Incoherence is due to scattering by equatorial jet.

Buijsman et al. (2017)

Ratio of incoherent to total semidiurnal band SSH variance



←As determined from altimeter wavenumber spectra by Zaron (2017)

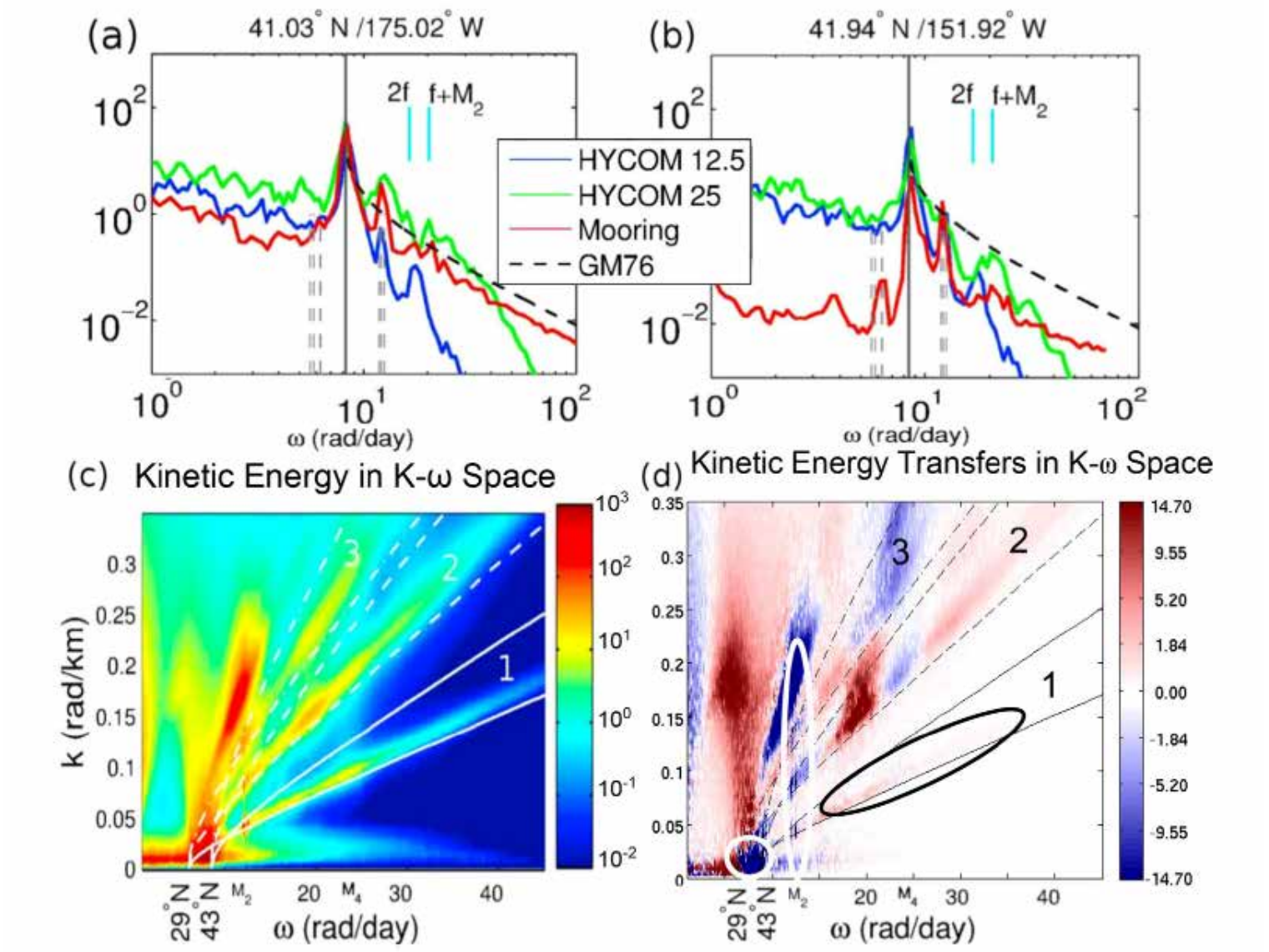
←As determined from HYCOM frequency spectra computed in Savage et al. (2017a).

Similar patterns in equator. Not-so-similar in strong mesoscale eddy regions.

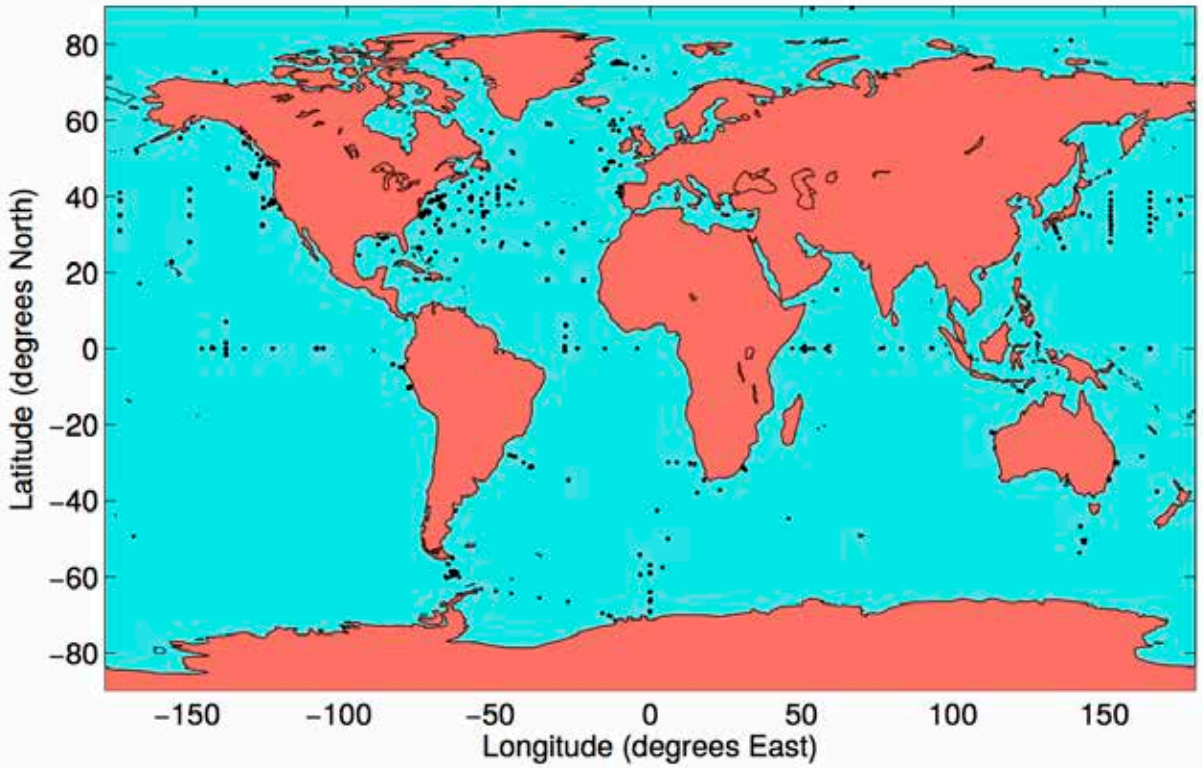
Nelson et al. (in preparation)

IGW continuum

First evidence of IGW continuum in models (Müller et al. 2015; updated figure given in Savage et al. 2017a)

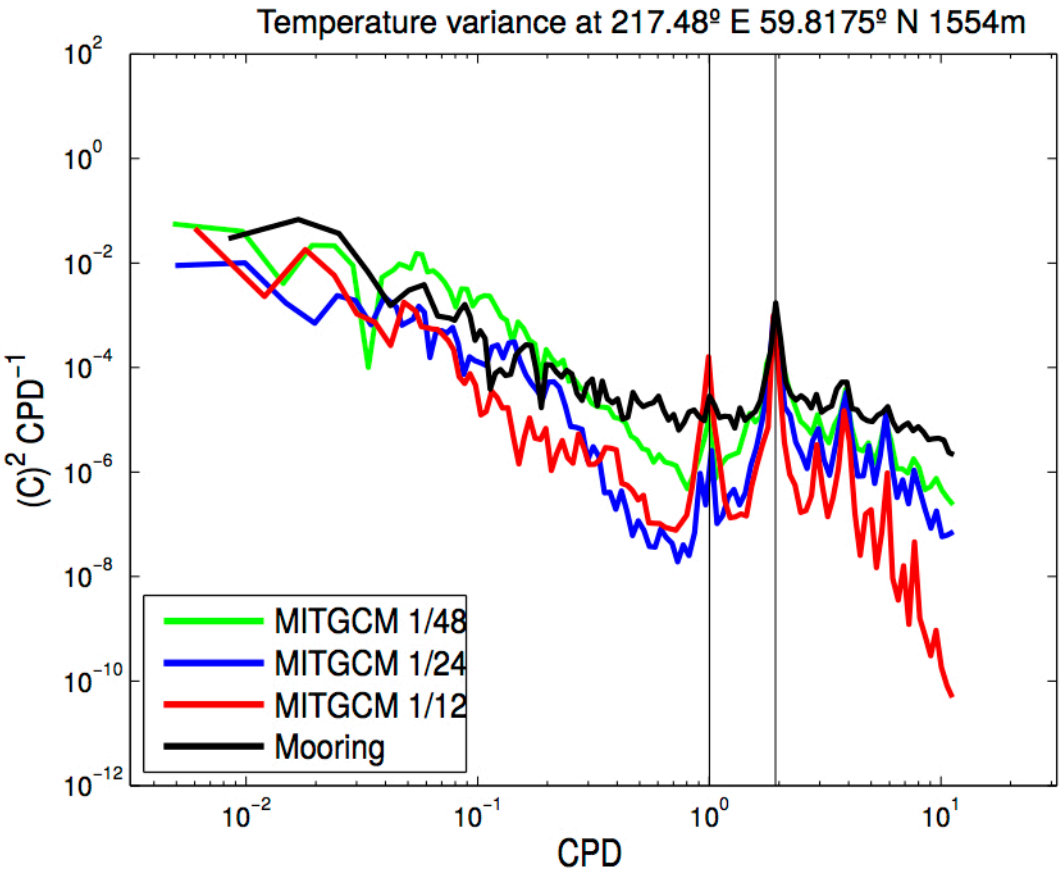


Locations of (thousands of) historical moored temperature and velocity time series observations

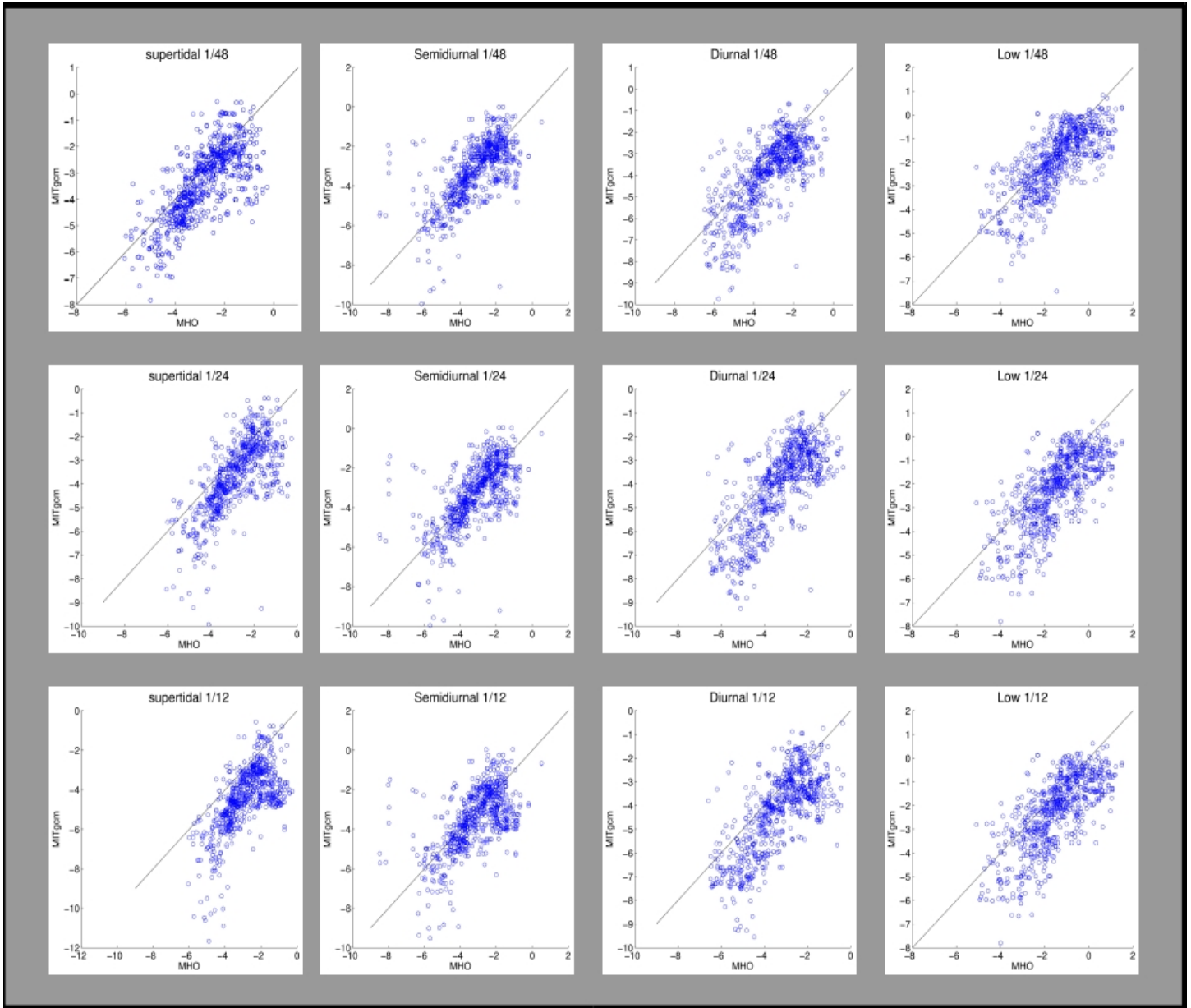


Luecke et al.,
in preparation

Example temperature variance spectra. Luecke et al., in preparation.



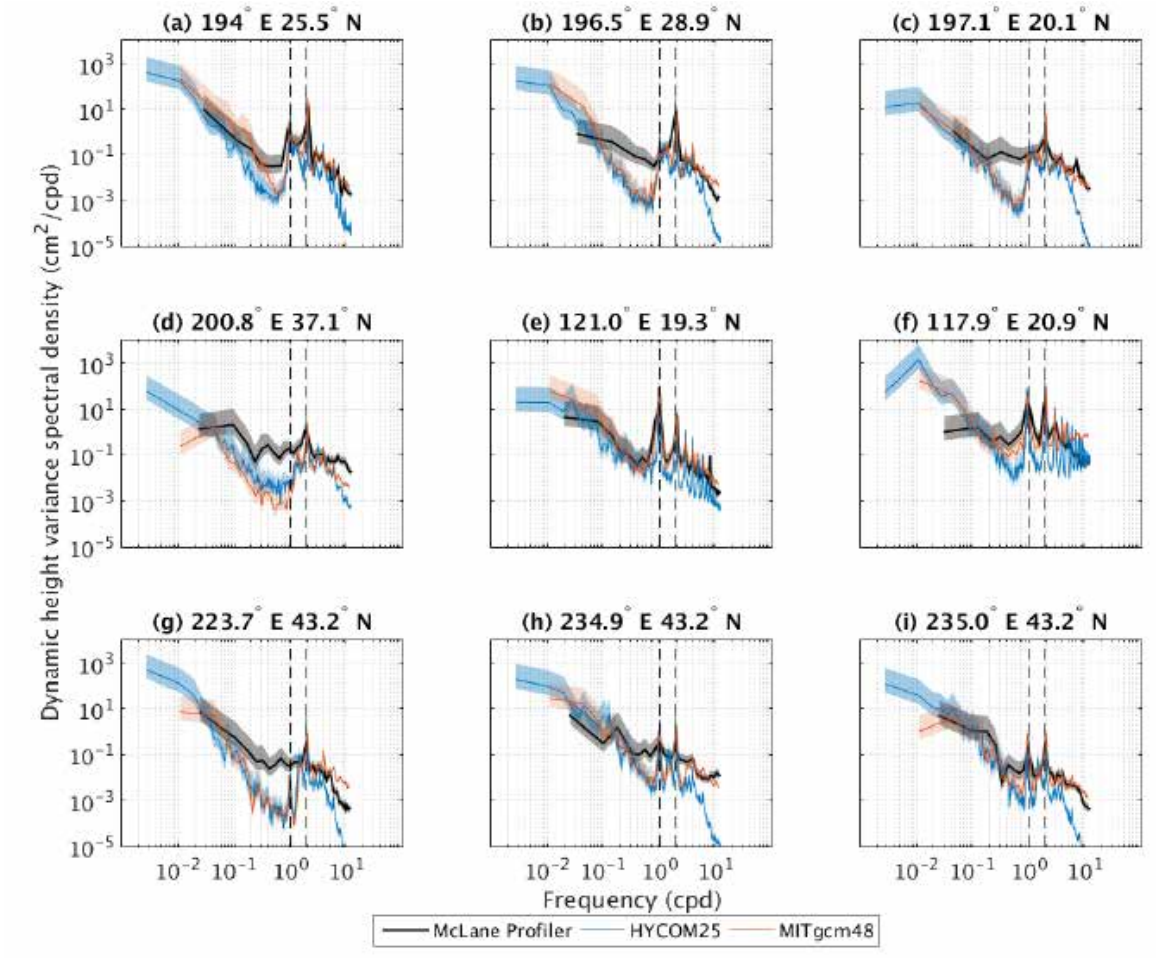
Band-integrated temperature variance in MITgcm vs. historical observations. Luecke et al., in preparation.



Units are $\log_{10}[(°C)^2]$

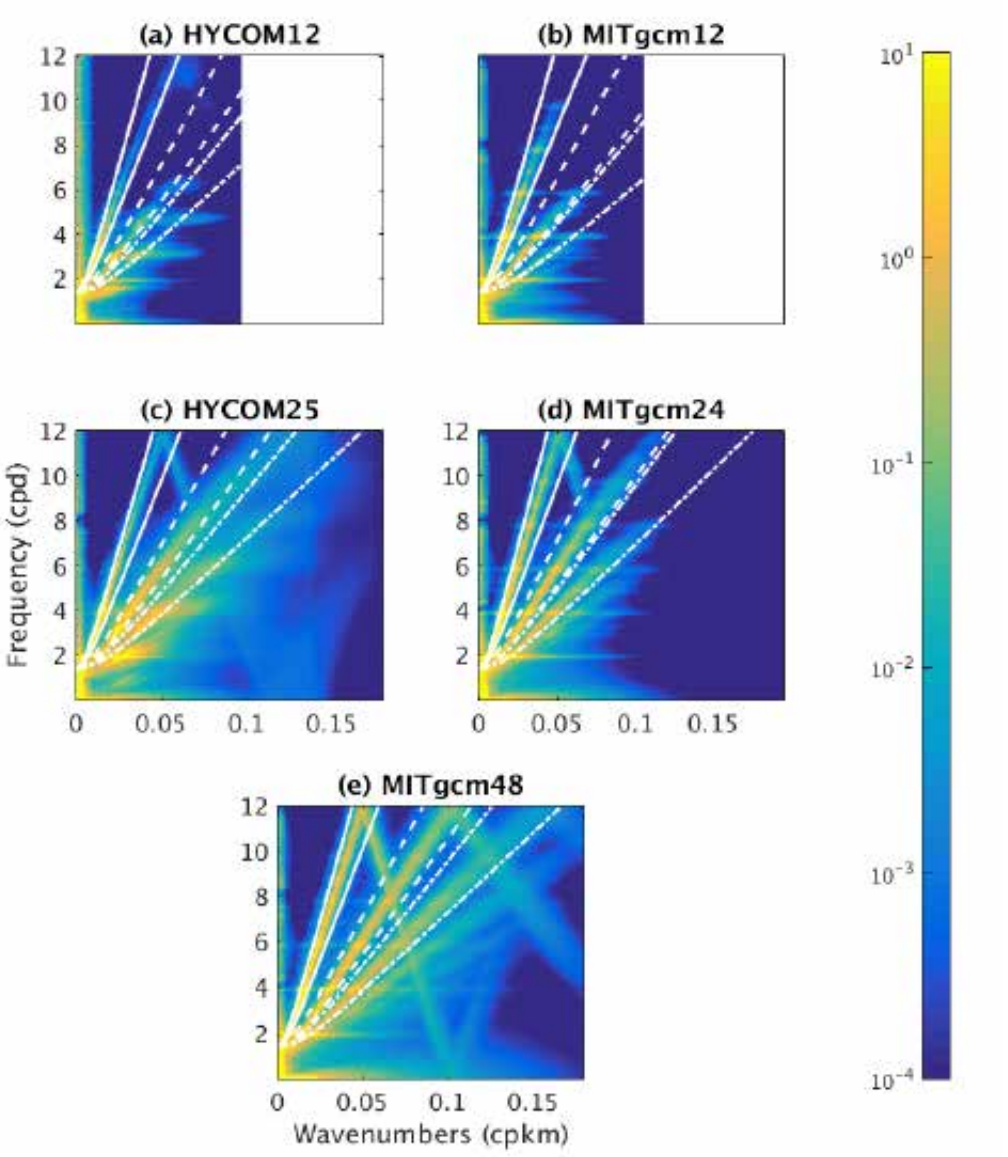
Kinetic energy results and HYCOM results (not shown) are similar

Dynamic height variance frequency spectra in 9 Pacific Ocean McLane profilers, 1/25° HYCOM, and 1/48° MITgcm

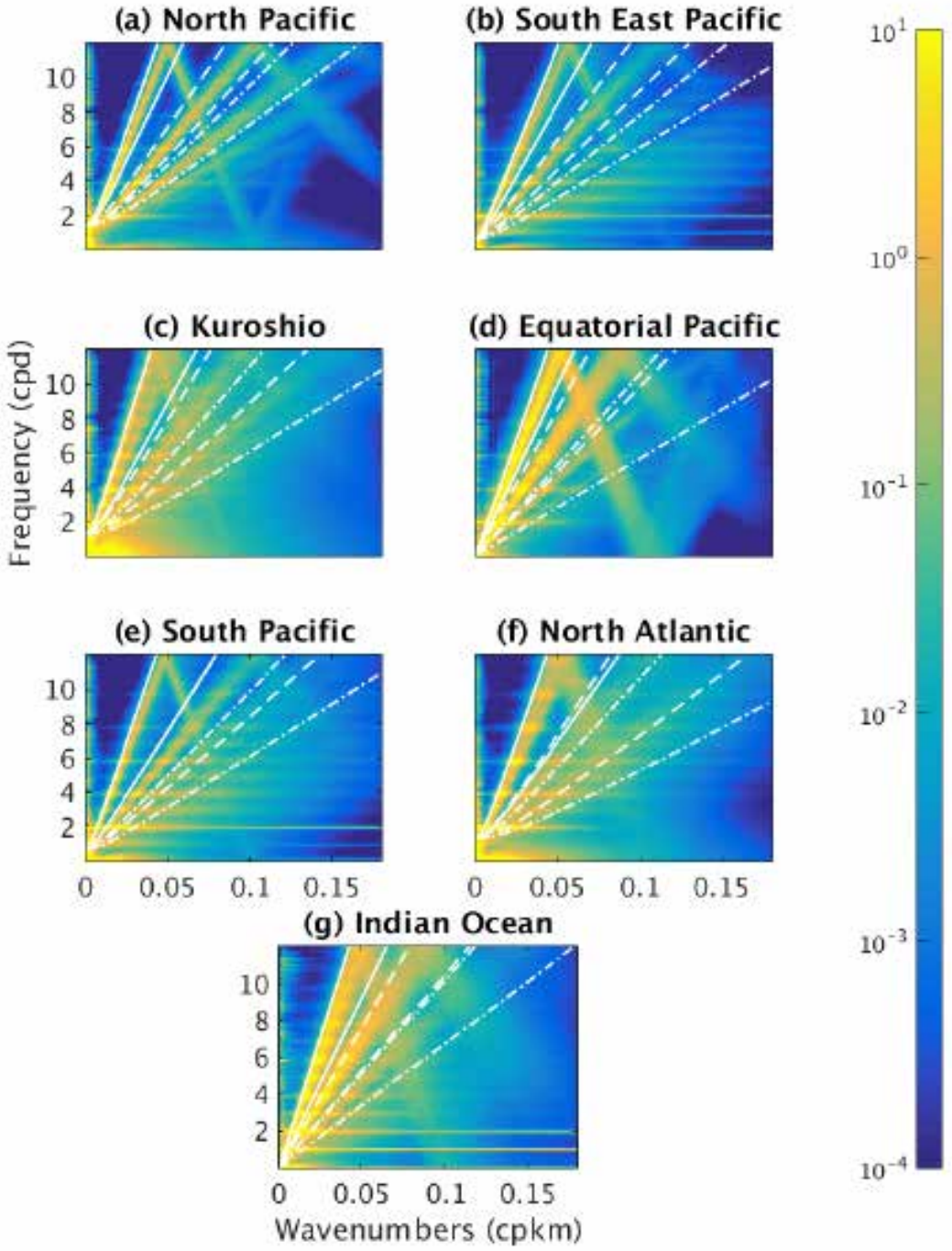


Savage et al. (2017b)

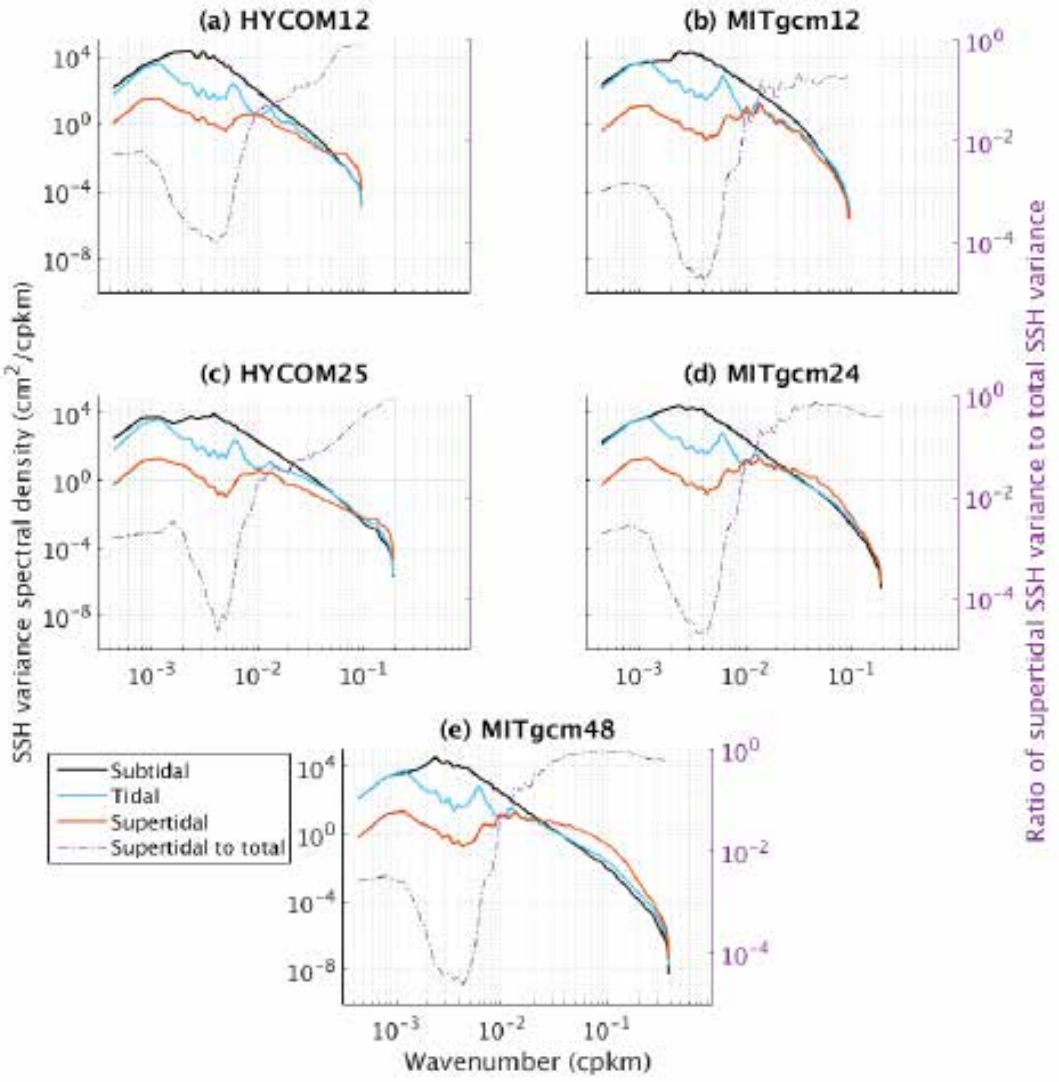
SSH variance frequency-horizontal wavenumber spectra density computed over North Pacific region from HYCOM and MITgcm simulations. Units are $\log_{10}[cm^2/(cpd * cpkm)]$. Savage et al. (2017b).



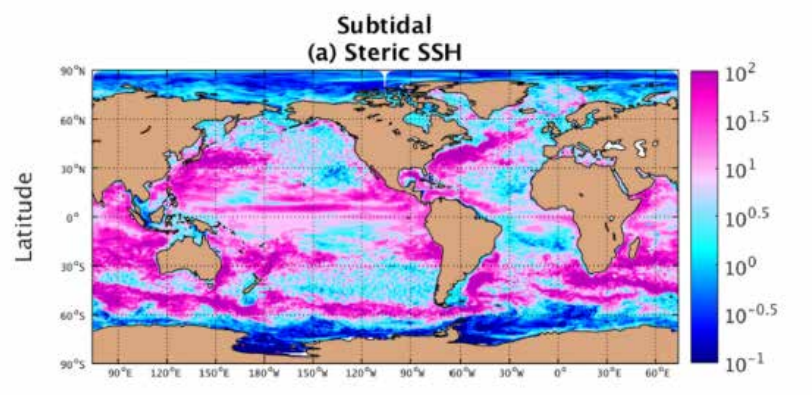
SSH variance frequency-horizontal wavenumber spectra density computed over seven regions from 1/48° MITgcm. Units are $\log_{10}[cm^2/(cpd * cpkm)]$. Savage et al. (2017b).

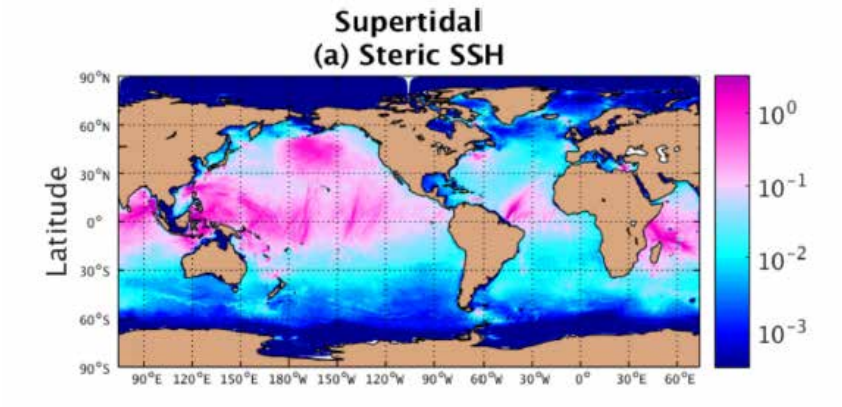


Horizontal wavenumber spectral density of SSH variance in Kuroshio region integrated over subtidal, tidal, and semidiurnal frequency bands in all five simulations. Savage et al. (2017b).

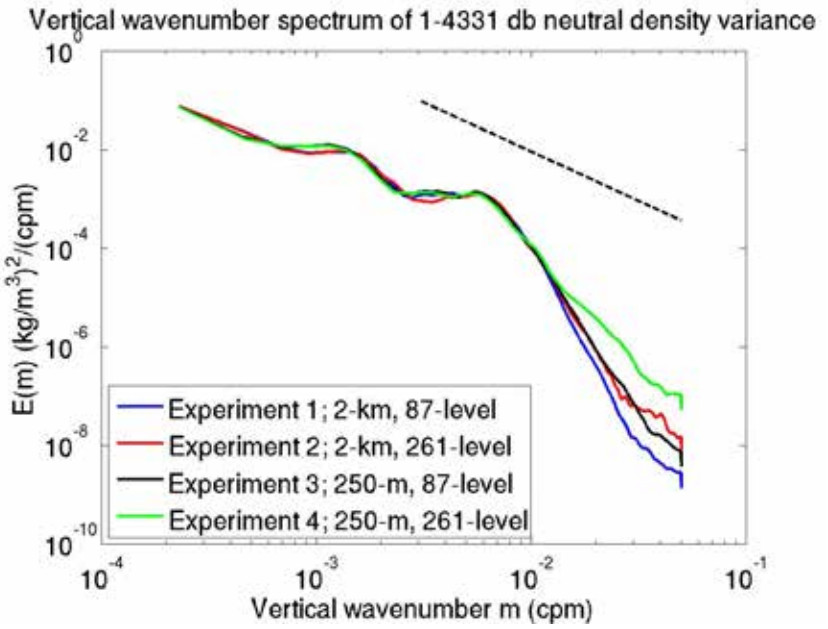


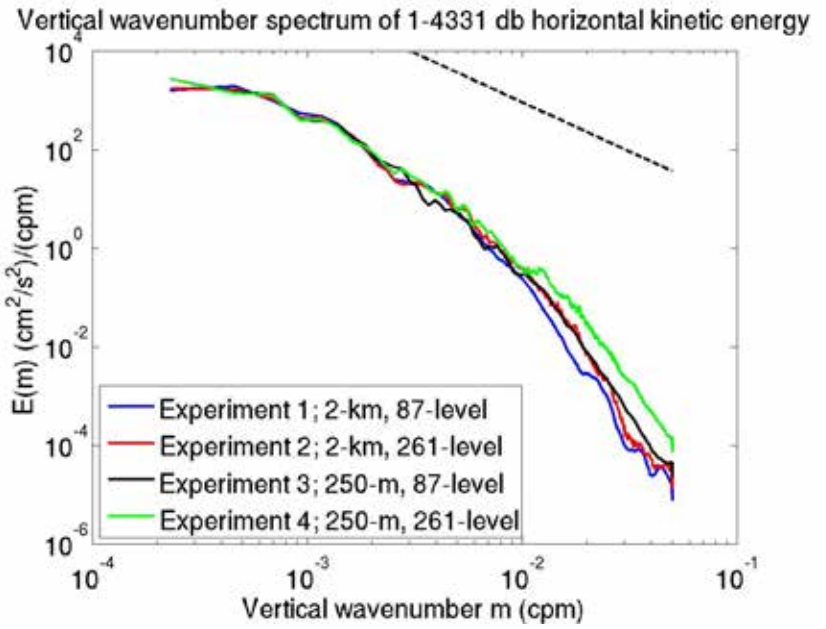
Global maps of band-integrated steric SSH variance (cm^2) in 1/25° HYCOM (Savage et al. 2017a)





Impact of vertical and horizontal resolutions on vertical wavenumber spectra (Ansong et al., in preparation; collaboration with Dimitris Menemenlis, Nicolas Grisouard, Dick Peltier, and others)





Vertical wavenumber spectra E(m) of 1-4331 db neutral density variance (left) and horizontal kinetic energy (right) in MITgcm simulations at a gridpoint near the SWOT fast phase California Current crossover point. Experiment 1 has horizontal and vertical resolutions equal to those of the global 1/48° MITgcm simulation. The other experiments have increasing vertical and horizontal resolutions, as indicated in the legend. Extra dashed line indicates predicted m^{-2} slope.

The Coastal Ocean Environment Summer School in Ghana (coessing.org)

Third summer school held in August 2017, at Regional Maritime University

Summary

- High-resolution simulations of HYCOM and MITgcm, with simultaneous atmospheric and tidal forcing, carry coherent internal tides, incoherent internal tides, and a partial IGW continuum.
- Comparison of simulations to observations and to theoretical predictions is ongoing.
- HYCOM has been used to make global maps of the SSH signatures of incoherent internal tides and the IGW continuum.
- DIDN'T SHOW, BUT: Wave drag is crucial for the accuracy of global internal tides in HYCOM. Wave drag not implemented in MITgcm.
- The 1/48° MITgcm simulation is being used to boundary force very-high-resolution regional patches.