High-resolution global modeling of the internal gravity wave spectrum

USING: Realistic HYCOM and MITgcm Simulations

SWOT Science Team Meeting 26-29 June 2017

Brian K. Arbic, University of Michigan

and many collaborators, including:
Matthew H. Alford, Scripps Institution of Oceanography
Joseph K. Ansong, University of Michigan
Maarten C. Buijsman, University of Southern Mississippi
Eric P. Chassignet, Florida State University
J. Thomas Farrar, Woods Hole Oceanographic Institution
James B. Girton, Applied Physics Laboratory
Conrad A. Luecke, University of Michigan
Dimitris Menemenlis, NASA JPL
Malte Müller, Norwegian Meteorological Institute
Hans E. Ngodock, Naval Research Laboratory
Amanda K. O'Rourke, University of Michgain
James G. Richman, Florida State University
Anna C. Savage, University of Michigan
Jay F. Shriver, Naval Research Laboratory
Harper L. Simmons, University of Alaska
Ole Martin Smedstad, QinetiQ North America, Stennis Space Center
Innocent Sououpgui, University of Southern Mississippi
Patrick G. Timko, Bangor University
Gunnar Voet, Scripps Institution of Oceanography
Alan J. Wallcraft, Naval Research Laboratory
Xiaobiao Xu, Florida State University
Luis Zamudio, Florida State University
Zhongxiang Zhao, Applied Physics Laboratory

Research sponsored by NASA, ONR, and NSF

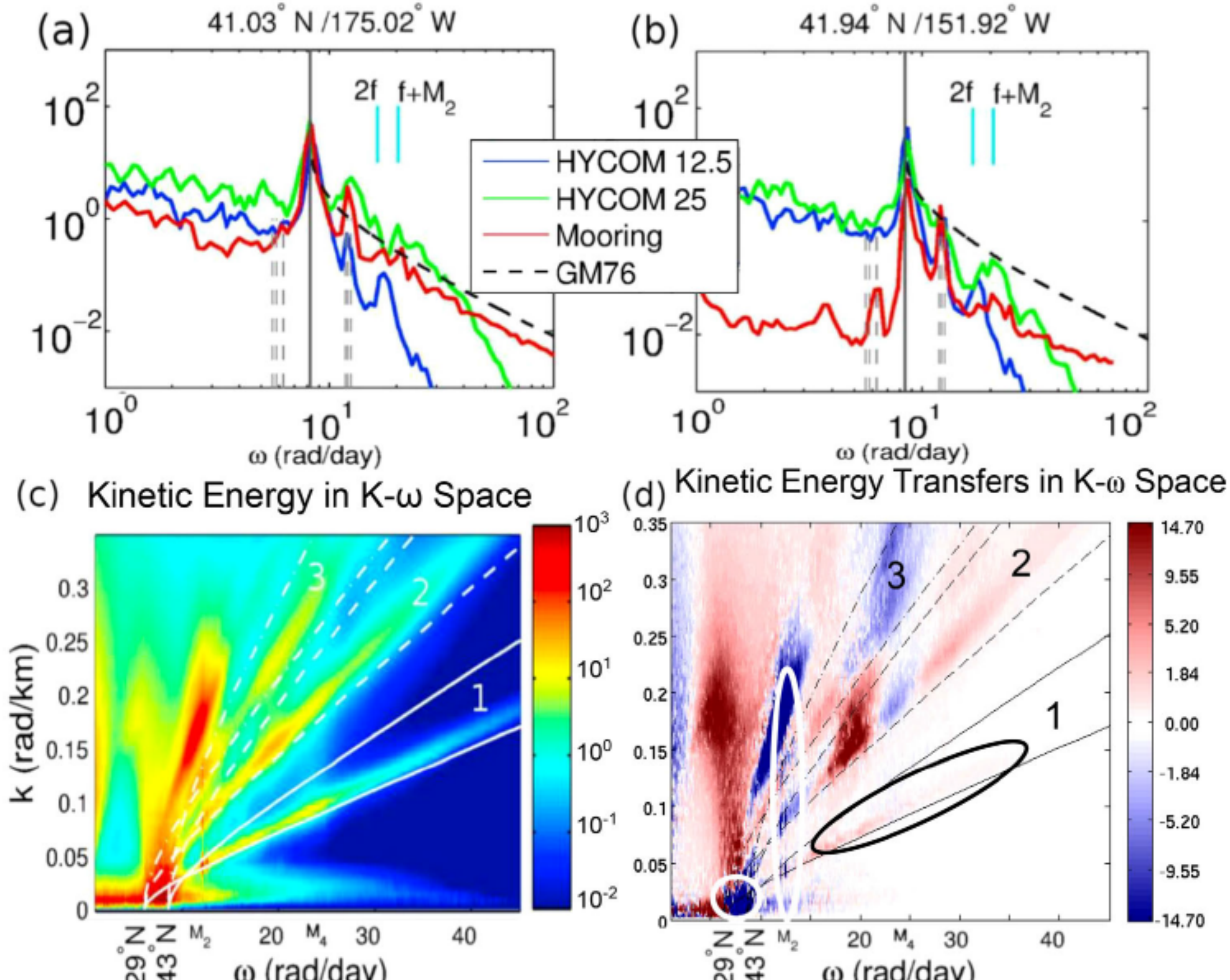
Background I: Relevance to SWOT

- High-frequency signals such as internal tides and the internal gravity wave (IGW) continuum will be an important signal in SWOT data, but will be temporally aliased.
- To reveal mesoscale eddy dynamics in SWOT data, internal tides and the IGW continuum must be accurately predicted and removed.

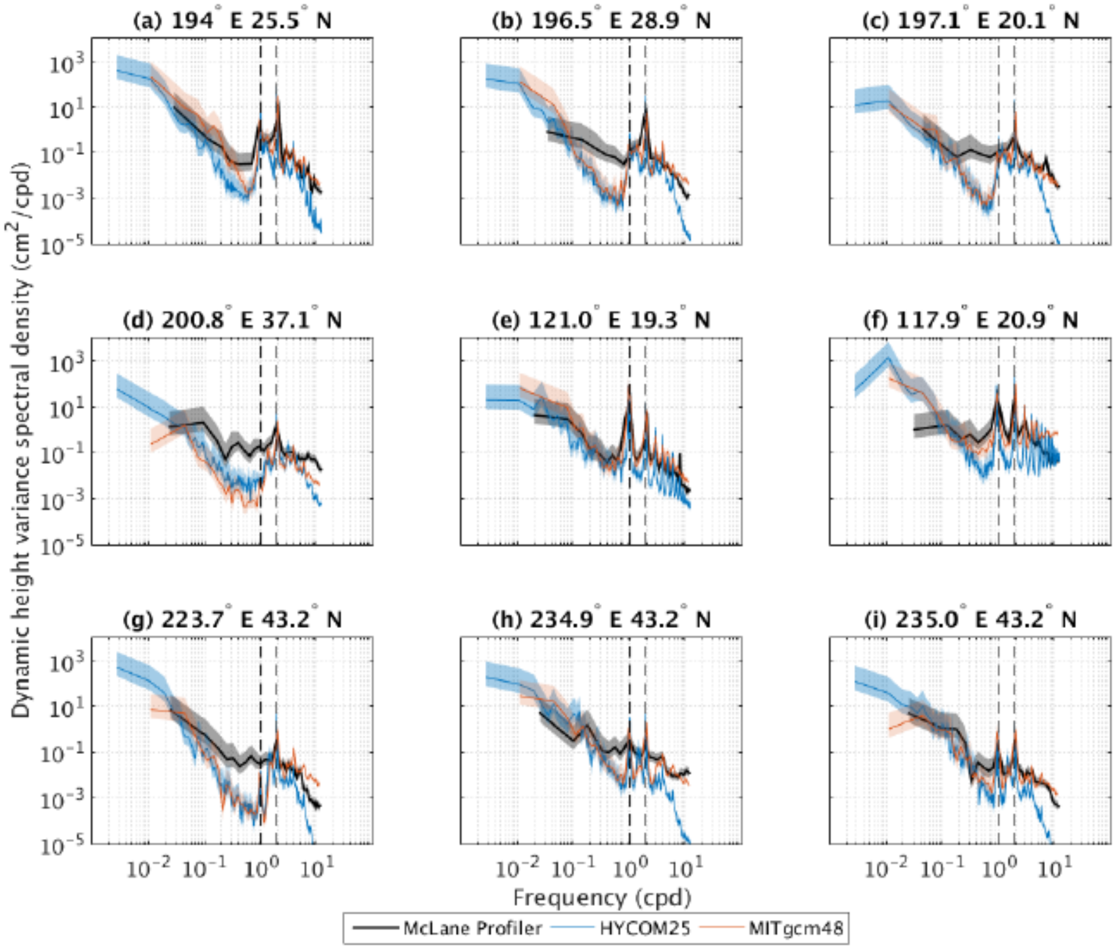
Background II: Global internal tide and IGW continuum modeling

- The IGW continuum is thought to be fed by near-inertial waves and internal tides, with nonlinear interactions filling out the spectrum.
- Producing an IGW continuum in models requires atmospheric forcing (to generate near-inertial waves), tidal forcing (to generate internal tides) , and high-resolution (to allow nonlinear interactions).
- The first high-resolution simulations with simultaneous atmospheric and tidal forcing were done with HYCOM (Arbic et al. 2010). This work built upon the first global internal tide models (Arbic et al. 2004, Simmons et al. 2004), which for simplicity employed tidal forcing only and a horizontally uniform stratification.
- Müller et al. (2015) first demonstrated, using HYCOM, that models with high resolution, atmospheric forcing, and tidal forcing, contained a partial IGW continuum.
- Several groups including ours are now examining the IGW continuum in MITgcm. We are also examining it in HYCOM.
- HYCOM has been compared to observations more often, has been published on more often, has more accurate tides, and has a data-assimilative machinery for both tides and eddies.
- The MITgcm simulations are run at higher horizontal and vertical resolution.
- Our group continues to compare both models to theory and to available observations.

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

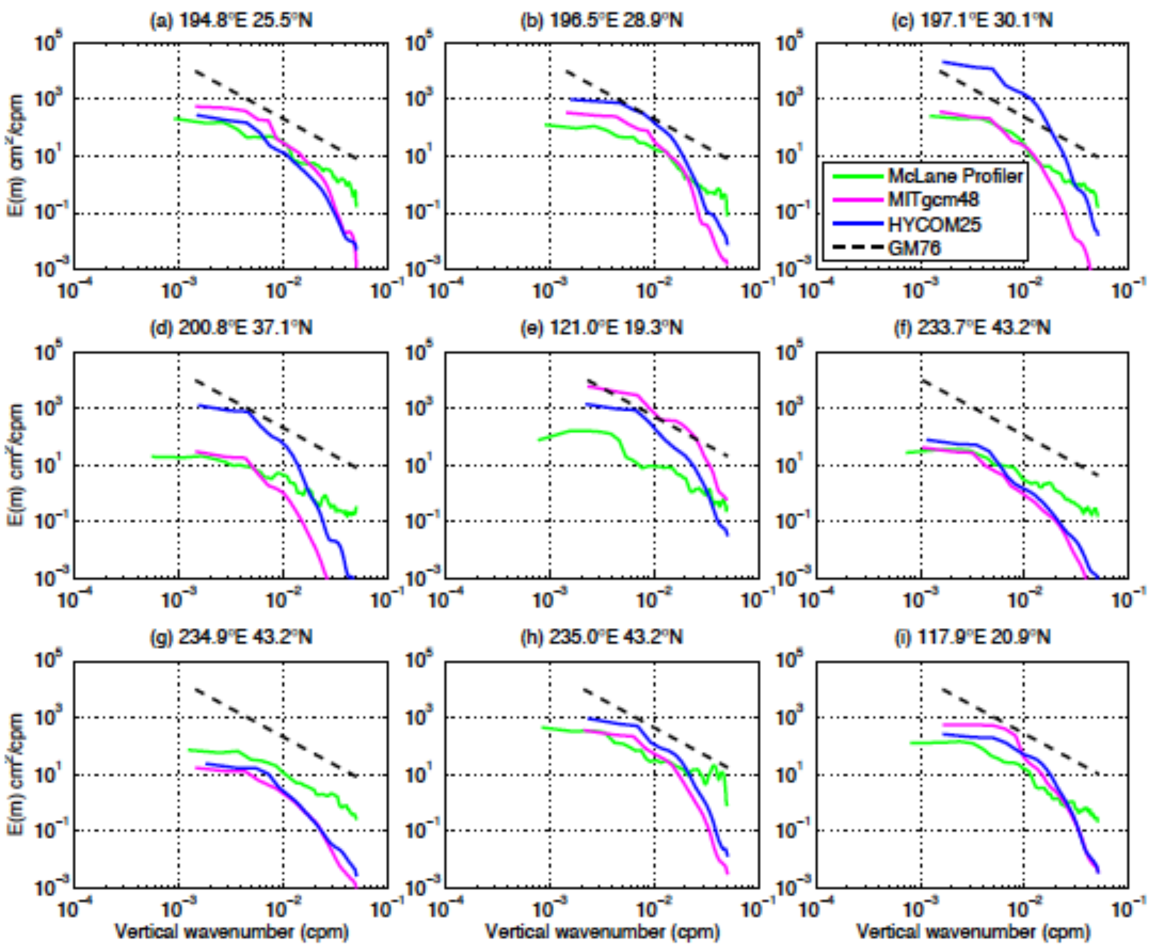


Dynamic height variance frequency spectra in 9 Pacific Ocean McLane profilers, 1/25° HYCOM, and 1/48° MITgcm



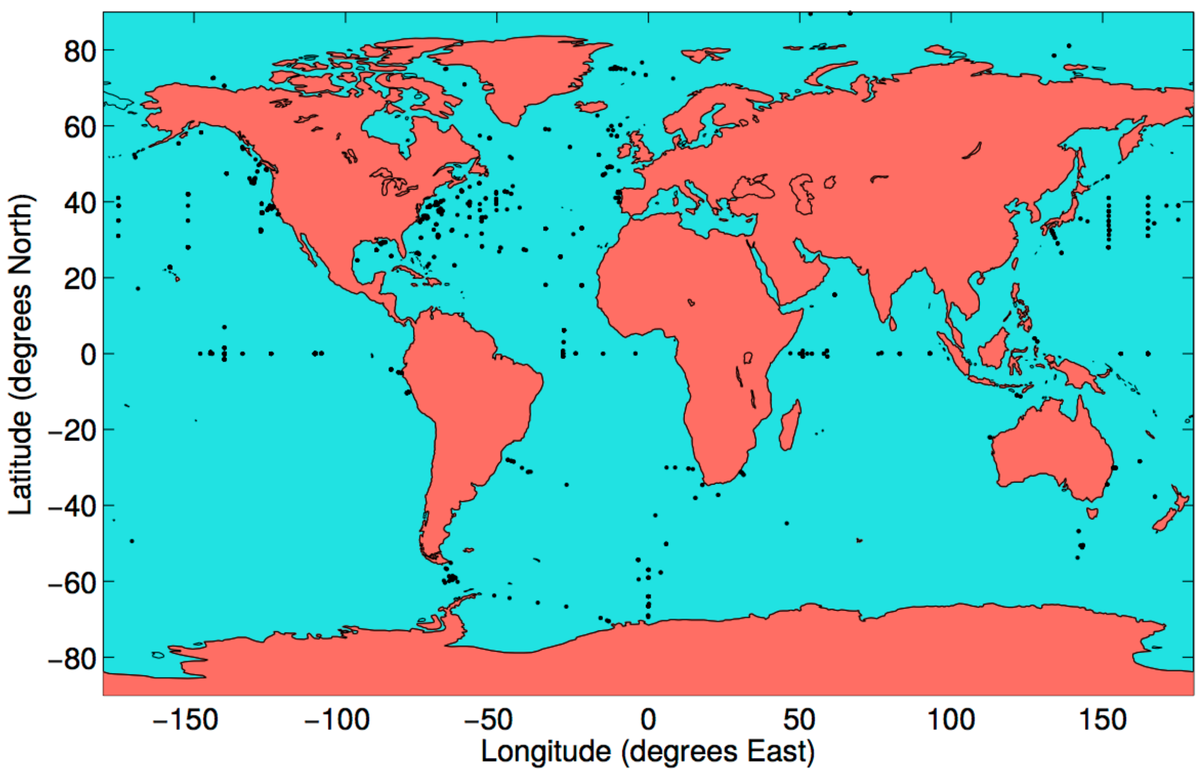
Savage et al., in revision

Vertical wavenumber spectra E(m) of horizontal kinetic energy from theory (black), McLane profiler observations (green), 1/48° MITgcm simulation (magenta), and 1/25° HYCOM simulation (blue), at 9 Pacific Ocean locations.



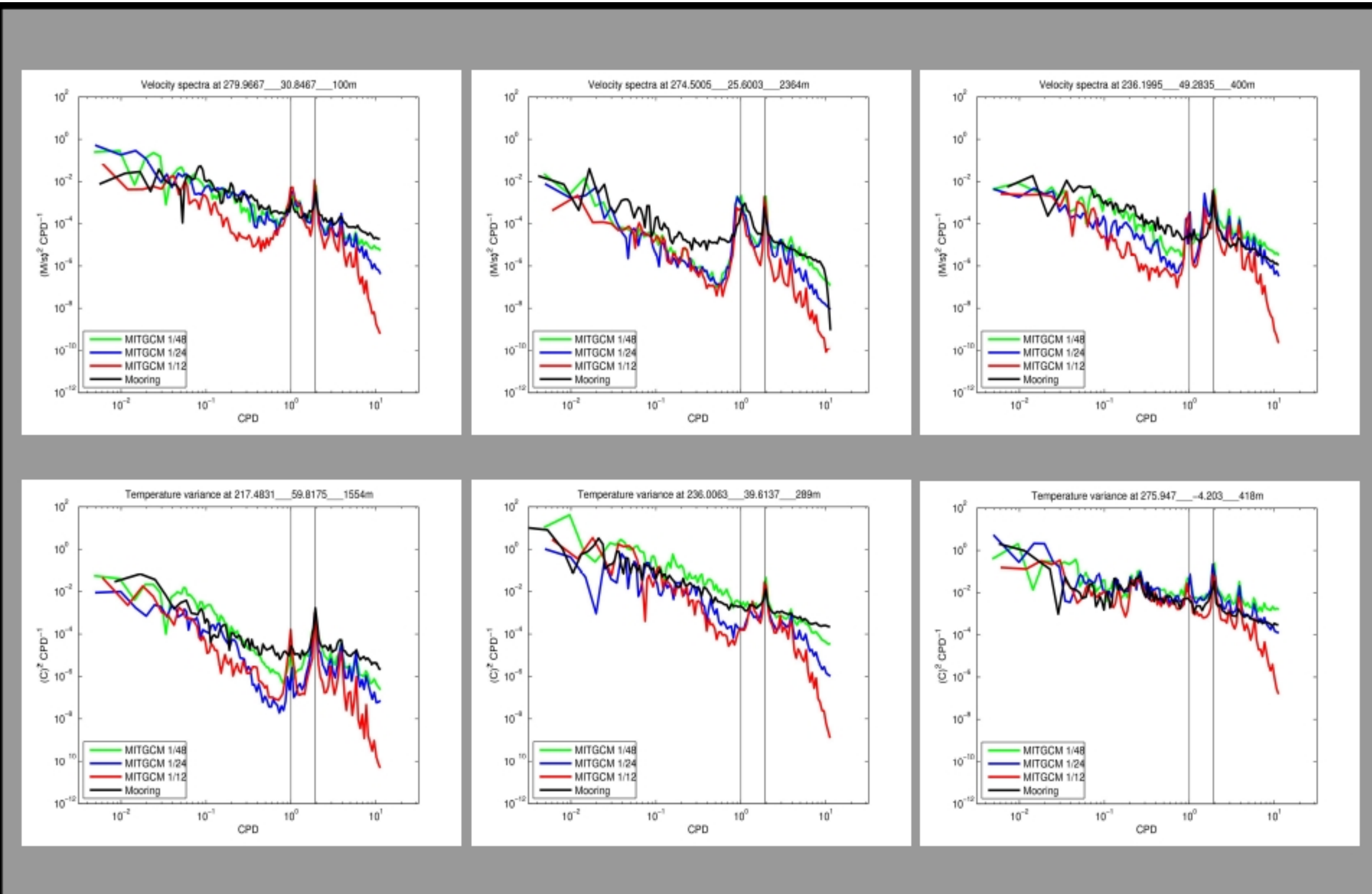
Ansong et al., in preparation

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

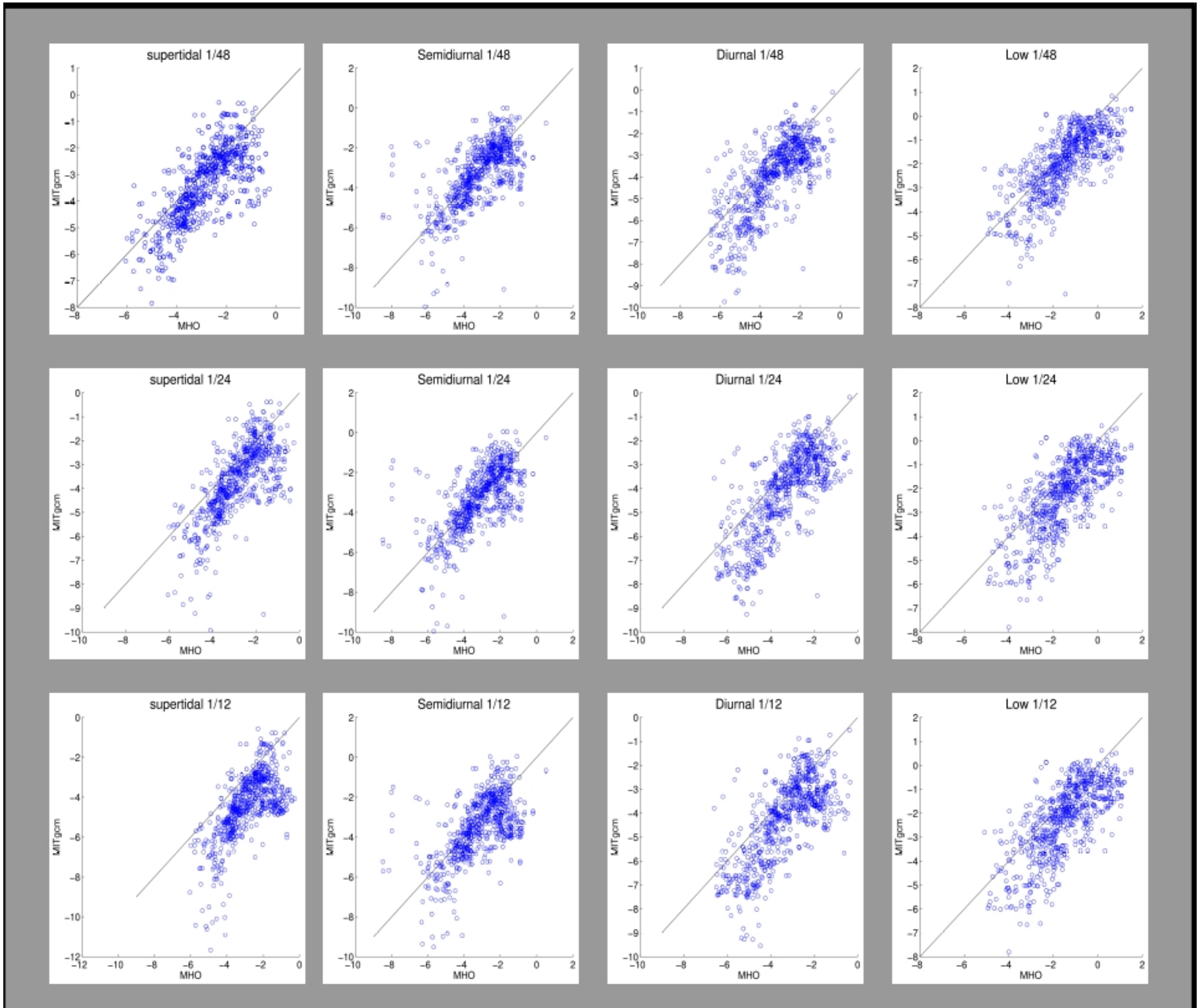


Luecke et al., in preparation

Example frequency spectra of kinetic energy and temperature variance in MITgcm vs. historical observations. Luecke et al., in preparation.

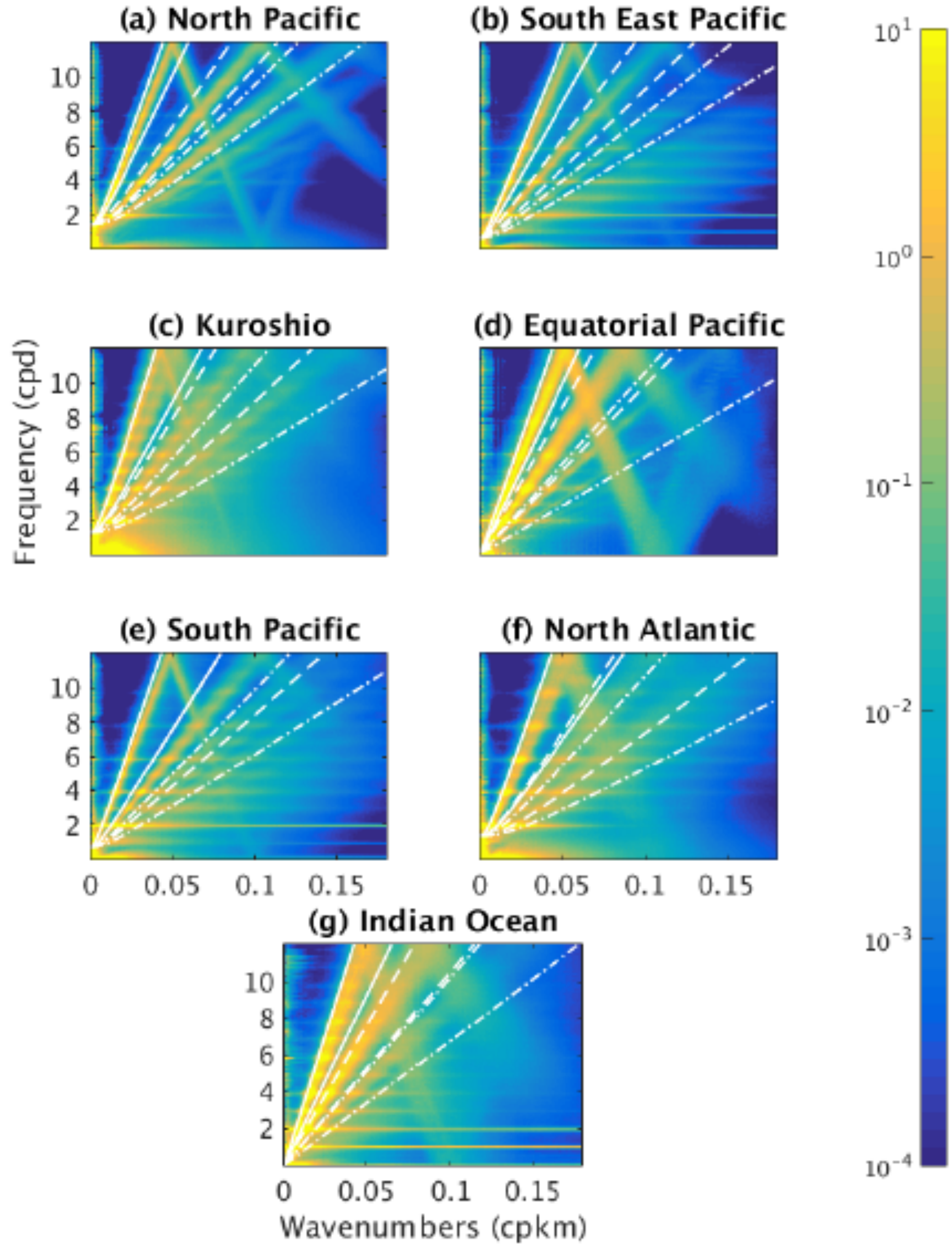


Band-integrated temperature variance in MITgcm vs. historical observations. Luecke et al., in preparation.

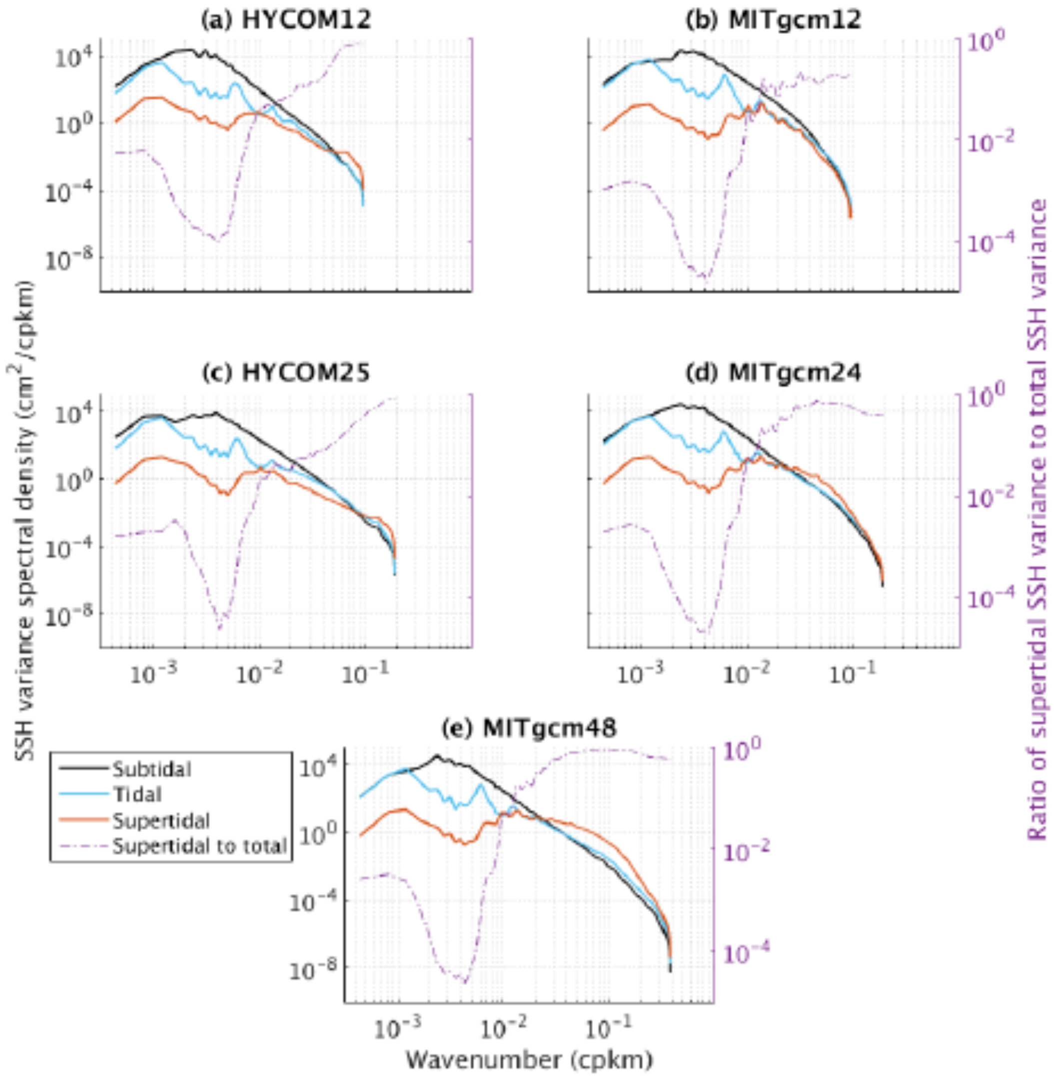


Units are $\log_{10}[(°C)^2]$

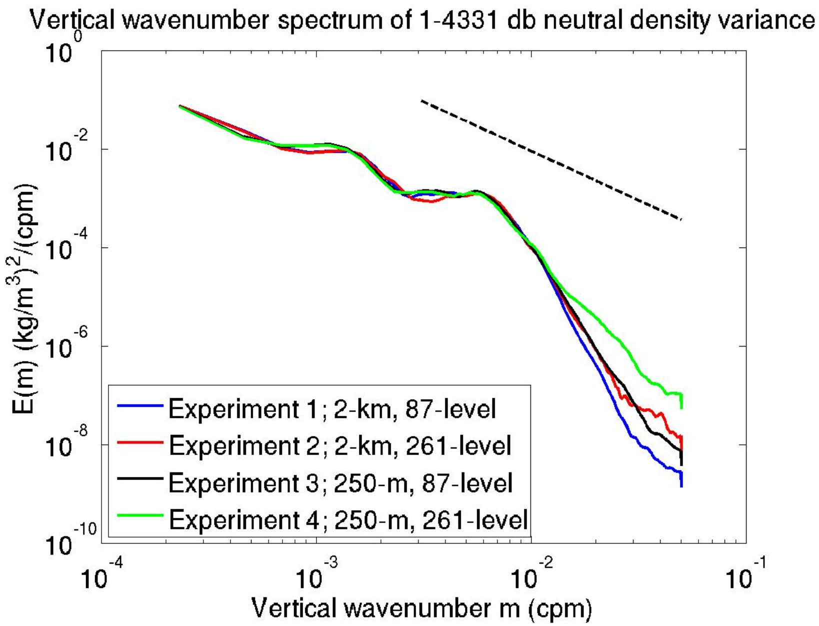
SSH variance frequency-horizontal wavenumber spectra density computed over seven regions from 1/48° MITgcm. Units are $\log_{10}[\text{cm}^2/(\text{cpd} * \text{cpkm})]$. Savage et al., in revision.

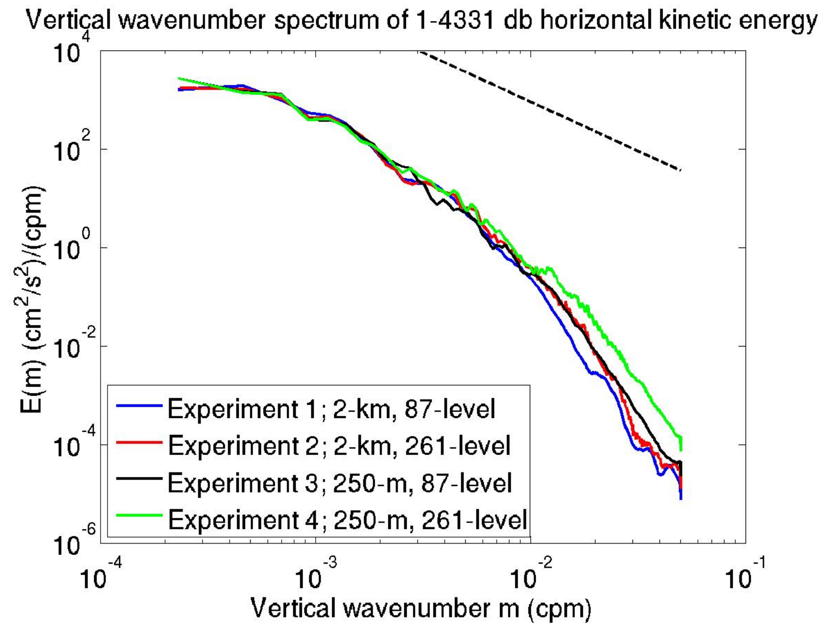


Horizontal wavenumber spectral density of SSH variance in Kuroshio region integrated over subtidal, tidal, and semidiurnal frequency bands in all five simulations. Savage et al., in revision.



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)

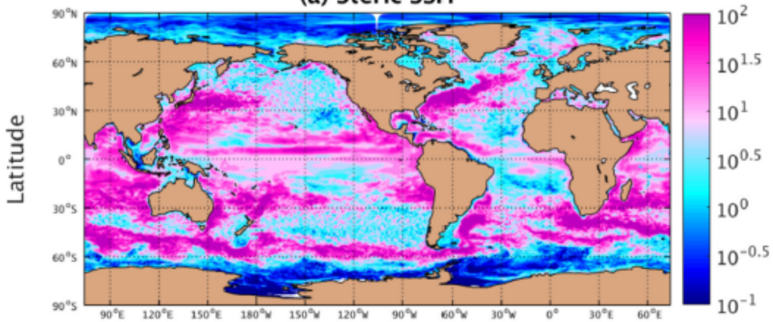




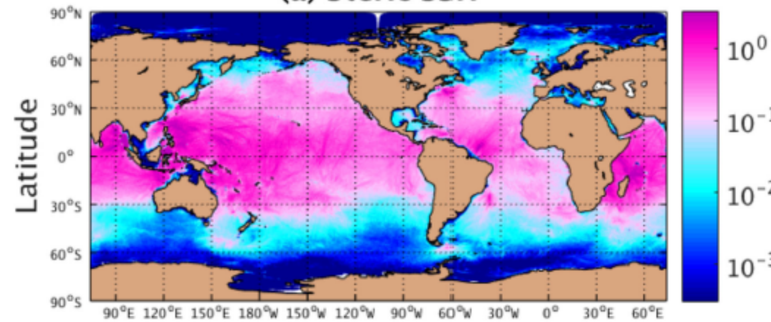
Vertical wavenumber spectra E(m) of 1-4331 db neutral density variance (left) and horizontal kinetic energy (right) in MITgcm simulations at a gridpoint near the SWOT fast phase California Current crossover point. Experiment 1 has horizontal and vertical resolutions equal to those of the global 1/48°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

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

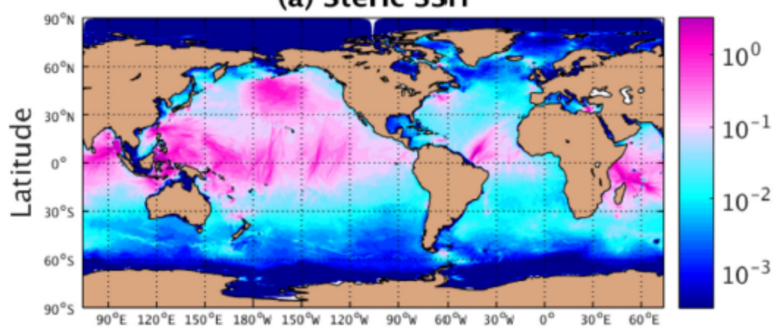
Subtidal
(a) Steric SSH



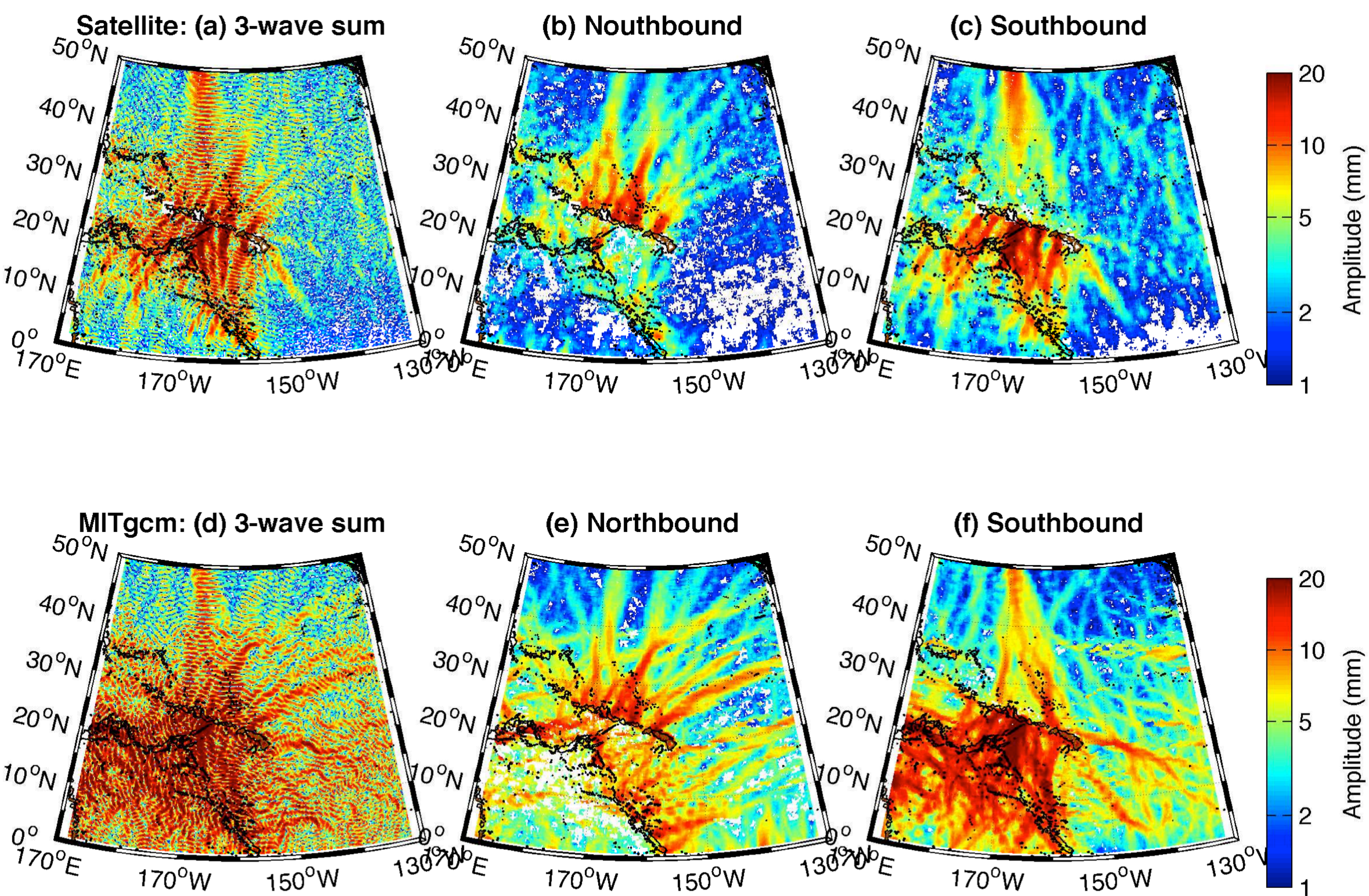
Semidiurnal Non-stationary
(a) Steric SSH



Supertidal
(a) Steric SSH



Internal tides in MITgcm (Dimitris Menemenlis) vs. altimetry (Zhongxiang Zhao)

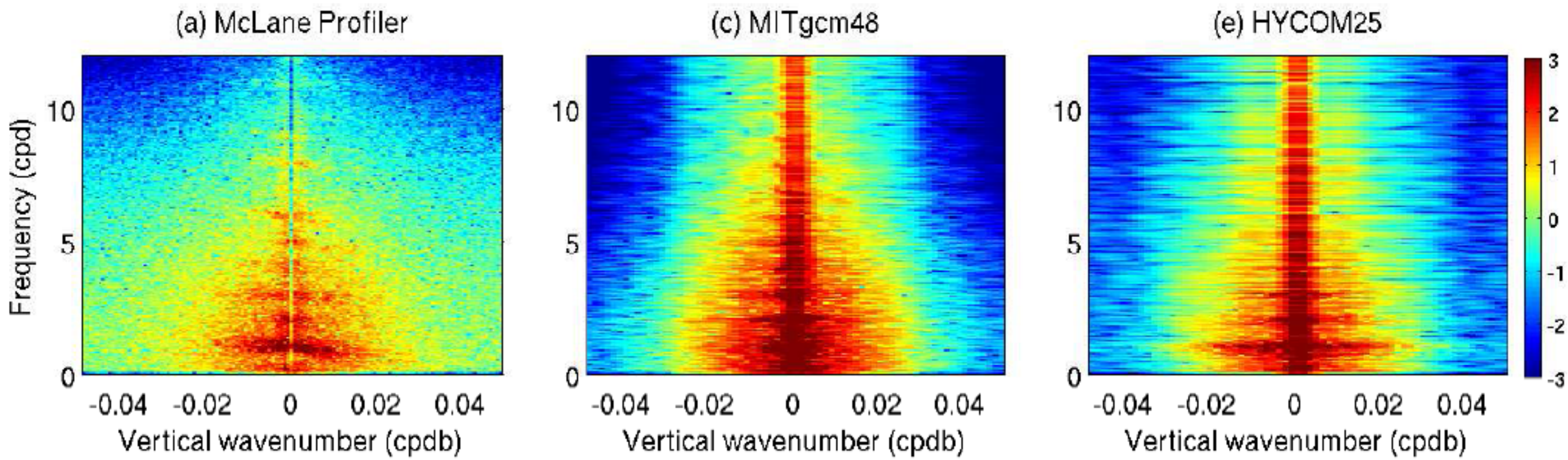


Summary

- High-resolution simulations of HYCOM and MITgcm, with simultaneous atmospheric and tidal forcing, have a partial IGW continuum.
- We are comparing the simulations to observations and to theoretical predictions.
- HYCOM has been used to make global maps of the SSH signatures of incoherent internal tides and the IGW continuum.
- Wave drag is crucial for the accuracy of global internal tide models, but has not been implemented in MITgcm.
- The 1/48° MITgcm simulation is being used to boundary force very-high-resolution regional patches.

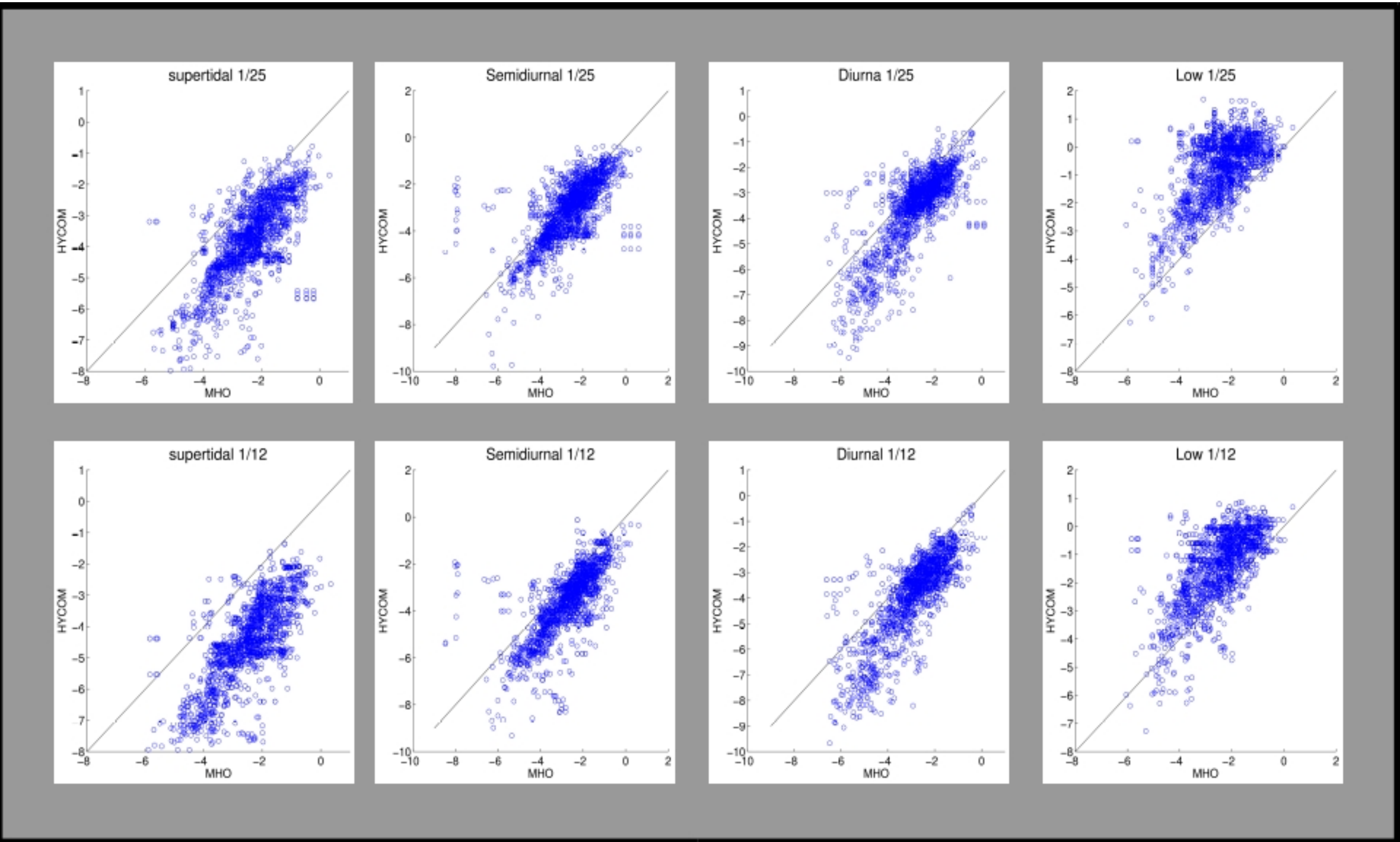
Extra slides

Frequency-vertical wavenumber spectra E(m,ω) of horizontal kinetic energy from McLane profiler observations (a), 1/48° MITgcm simulation (b), and 1/25° HYCOM simulation, at location 121.0°E, 19.3°N.

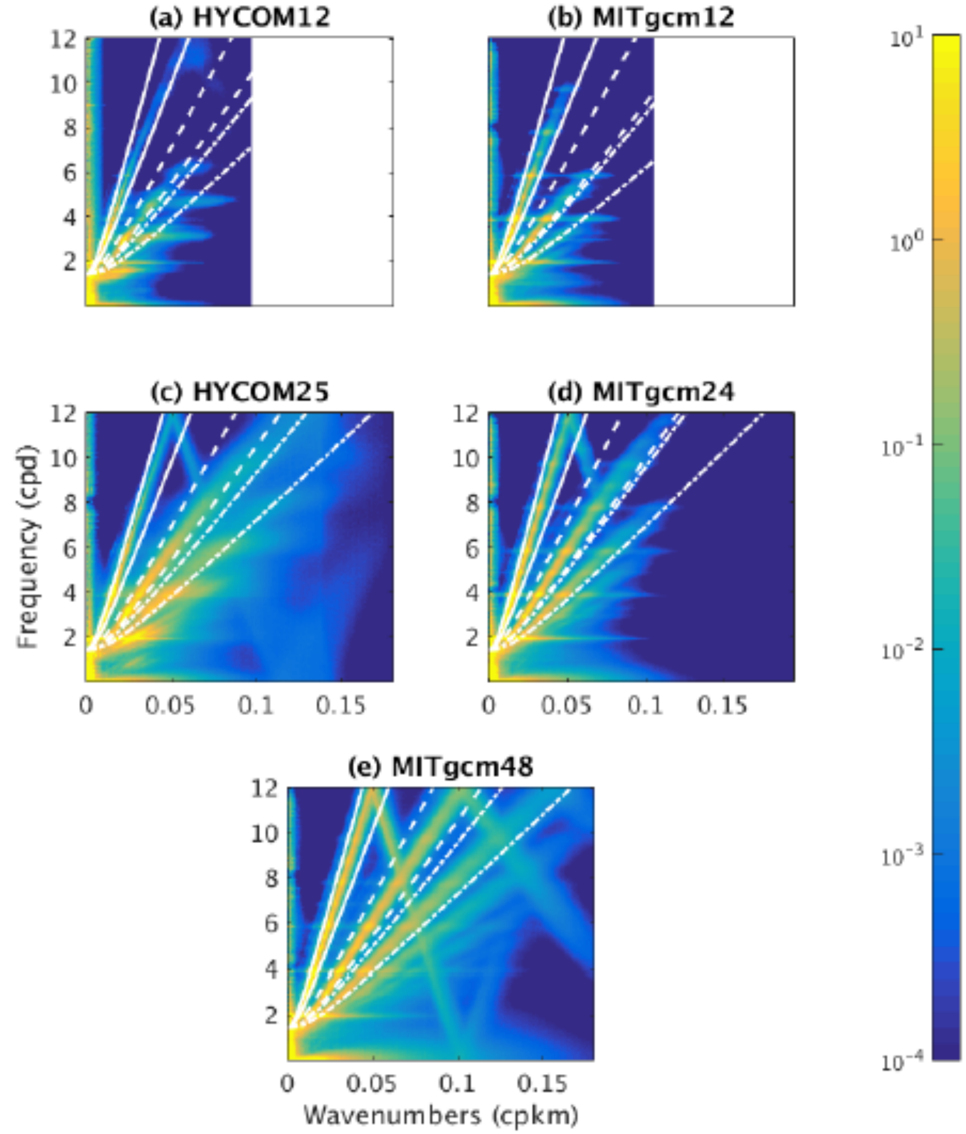


Units are $\log_{10}[(cm/s)^2/(\text{cycle per day} * \text{cycle per db})]$. The near-symmetry about the x-axis implies nearly equal amounts of upward- and downward-propagating energy. Ansong et al., in preparation.

Band-integrated temperature variance in HYCOM vs. historical observations. Luecke et al., in preparation. Units are $\log_{10}[(°C)^2]$.



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., in revision.



Impact of damping on low-mode internal tides (Ansong et al. 2015)

AGU Journal of Geophysical Research: Oceans 10.1002/2015JC010998

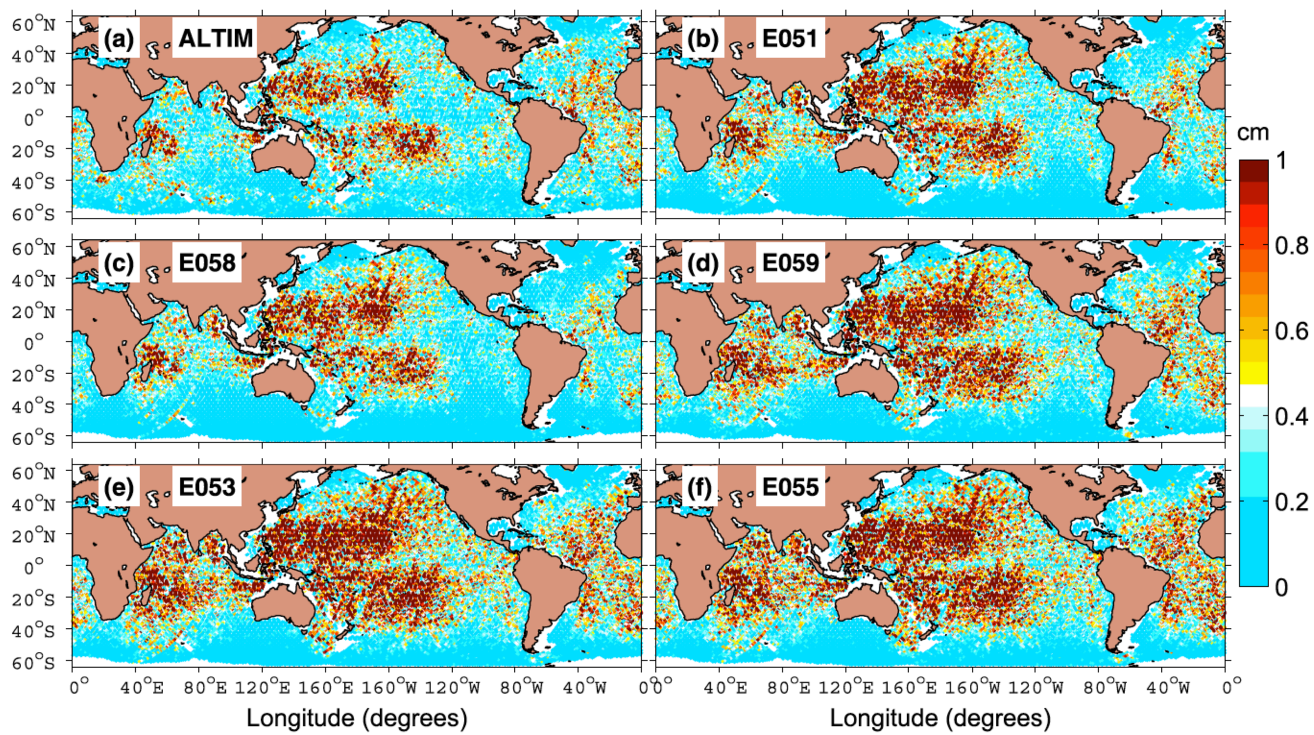


Figure 5. Amplitude (cm) of M_2 internal tide in (a) along-track altimeter-based analyses, and in HYCOM simulations (b) E051; with wave drag (scale factor = 0.5) applied to the bottom flow, (c) E058; with wave drag (scale factor = 1.0) applied to the bottom flow, (d) E059; with wave drag (scale factor = 1.0) applied to only the barotropic flow, (e) E053; without wave drag, (f) E055; without wave drag but with quadratic bottom friction increased by about 100 times along the continental shelves. The amplitudes of the HYCOM simulations are computed from 3 months of SSH output.