Comparison of internal tides and gravity waves in global/basin-scale models and observations

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and many co-authors

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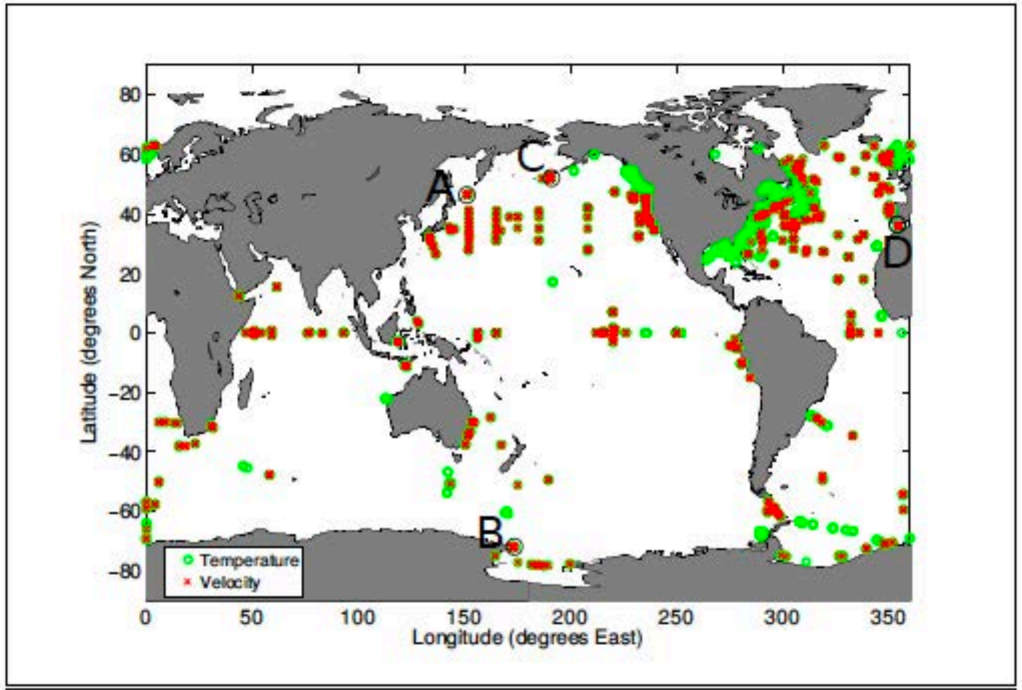
Background and motivation

- Global- and basin-scale models with eddying resolution + atmospheric forcing fields + tidal forcing are still relatively new.
- They are being used for many applications including planning for SWOT and the velocity-measuring missions S-MODE/SKIM/WACM.
- In addition to US HYCOM + MITgcm simulations, there are now some simulations of this type in France—North Atlantic 1/60° (Grenoble), global 1/12° (Toulouse).

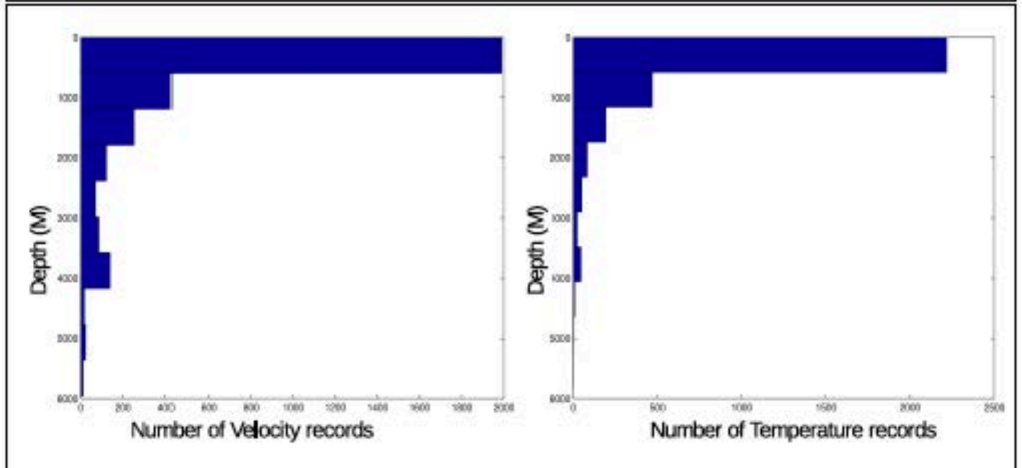
- Important to compare such models to observations.

- Will show some new comparisons here.

Models vs. mooring archive (Luecke et al., in review)



Geographical distribution



Vertical distribution

Compute frequency spectra of temperature variance and KE in:

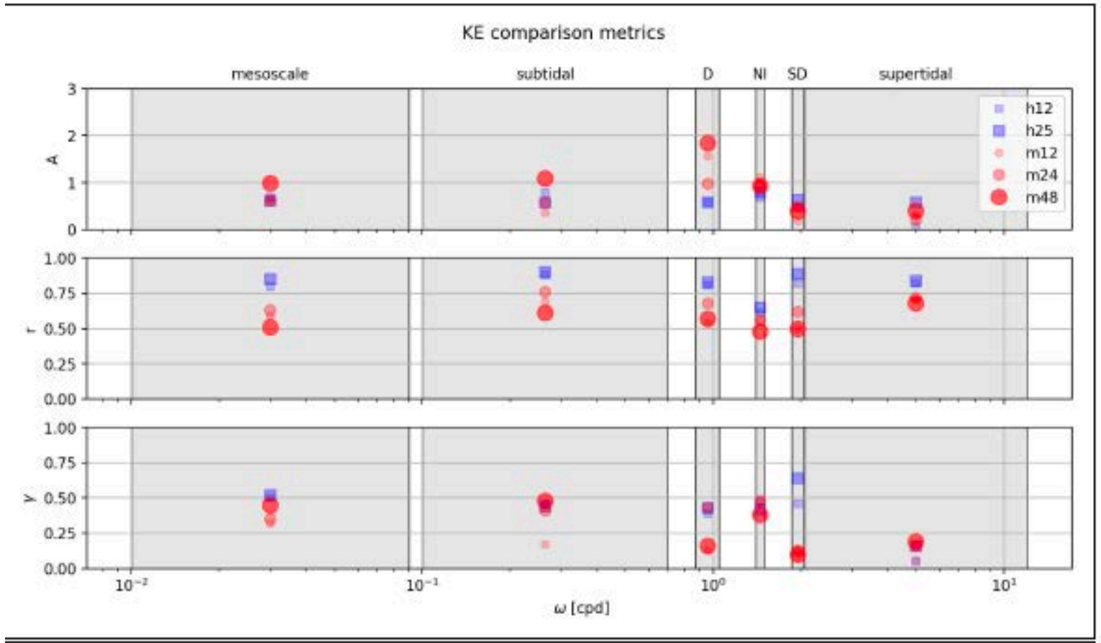
- --moorings
- --1/12.5° + 1/25° HYCOM
- --1/12° + 1/24° + 1/48° MITgcm

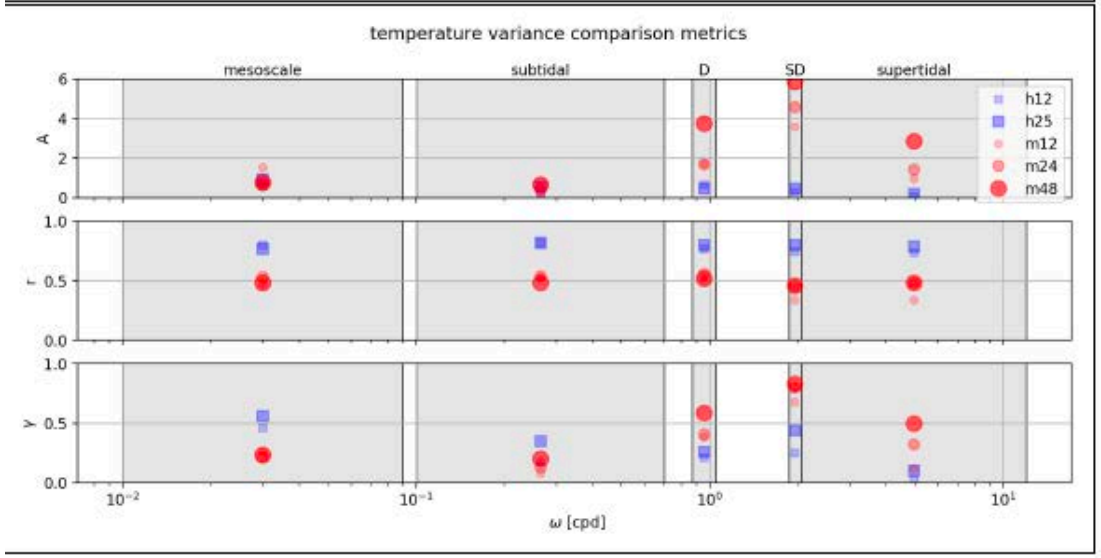
Integrate across bands of interest:

- --mesoscale
- --subtidal
- --diurnal
- --near-inertial
- --semidiurnal
- --supertidal

Make scatterplots, compute correlation coefficients and other statistics

Models vs. mooring archive(Luecke et al., in review)





Correlation coefficients, KE

Correlation coefficients, temperature variance

1/12.5° + 1/25° HYCOM (bluish symbols) has a higher spatial correlation with observations than
1/12° + 1/24° + 1/48° MITgcm (orange/red symbols),
across all frequency bands examined

Why?

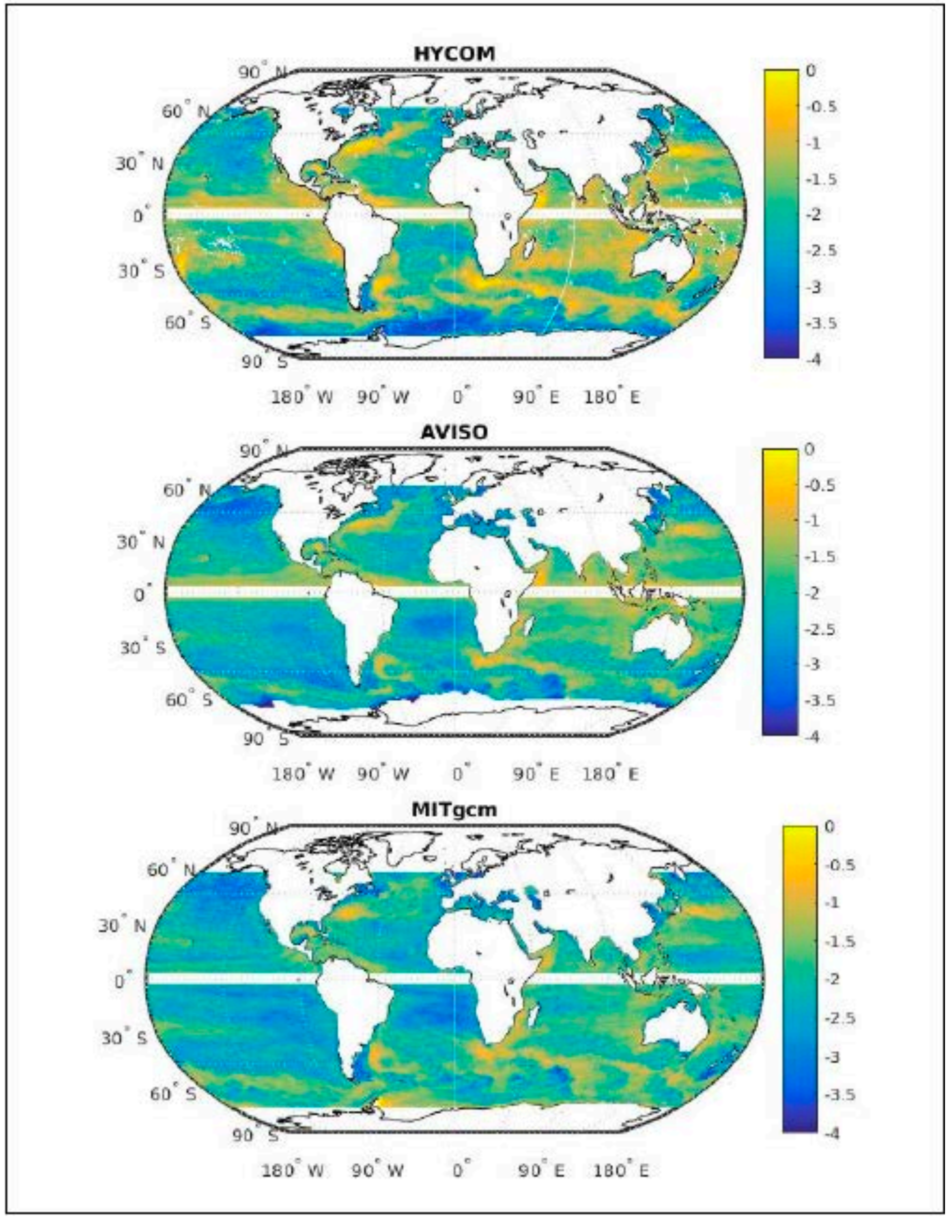
Speculation: as an operational model, HYCOM has been tuned to accurately capture western boundary currents, stratification, etc.

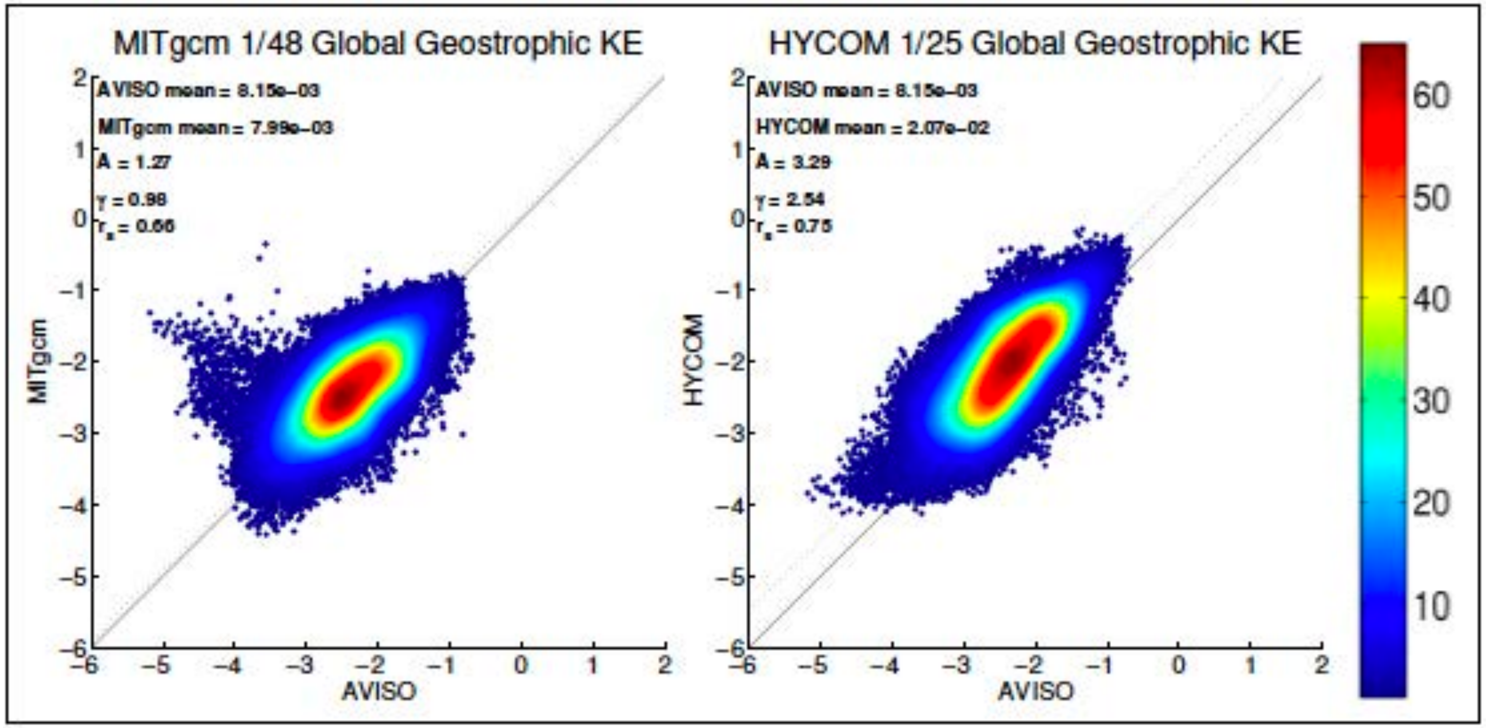
Advantage of MITgcm lies in supertidal band—more realistic energy levels (consistent with Savage et al. 2017)

Models vs. AVISO (Luecke et al., in review)

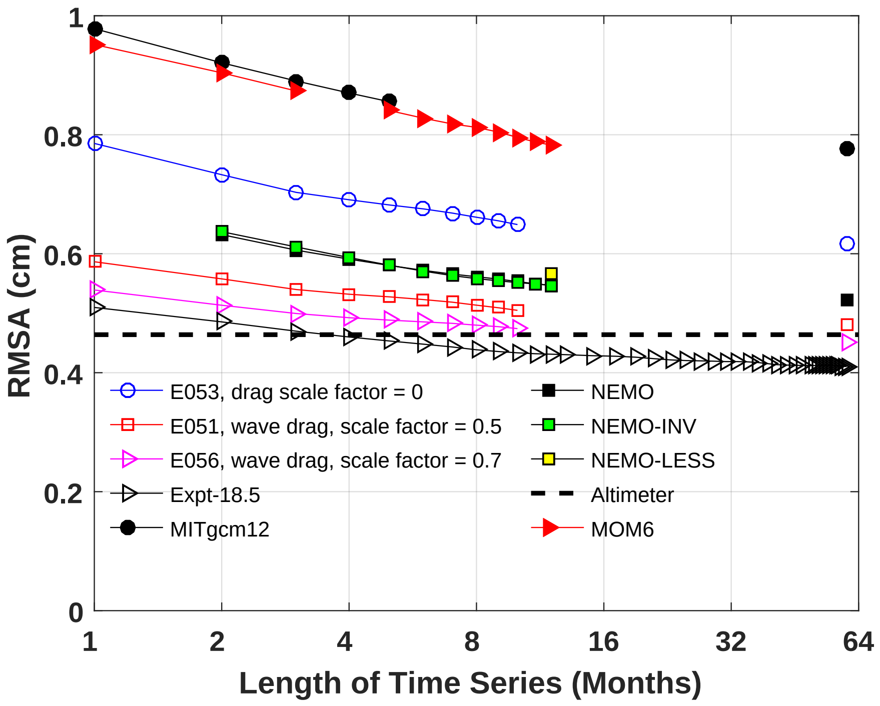
Use AVISO to get more spatial coverage for a specific band (low-frequency geostrophic flow).

HYCOM has higher spatial correlation but too much energy, relative to AVISO.





Globally averaged M_2 internal tide SSH amplitudes (cm) in global hydrodynamical models and along-track altimetry (Ansong et al., in preparation)



Ansong et al., paper in preparation

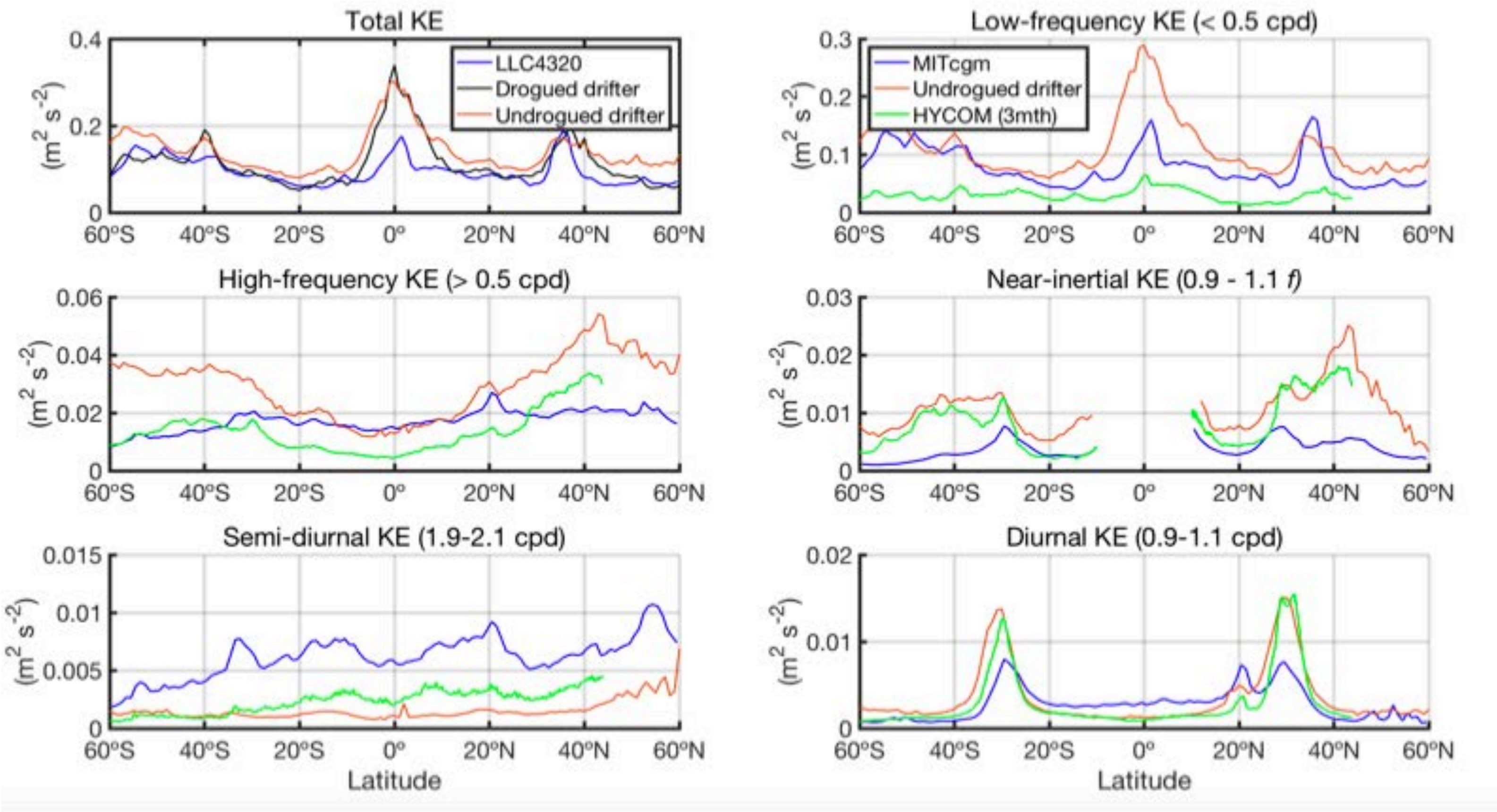
Luke Kachelein's PhD work: Explains the roll-off of stationary internal tide with record length.
Go see his poster!

Jérôme Chanut demonstrates that global 1/12° NEMO compensates for missing wave drag through explicit and implicit numerical dissipation
Go see his poster!

Tidal forcing in MITgcm runs

- Overly large barotropic and internal tides are in part due to lack of wave drag.
- But large errors in the barotropic tides also stem from the astronomical forcing.
- The intent was to solve du/dt + … = $-\nabla(\eta-\eta_{EQ}-\eta_{SAL})$, with the SAL term η_{SAL} approximated by $0.1121*\eta$ (scalar approximation)
- Instead they solved du/dt + … = $-\nabla(\eta-1.1121*\eta_{EQ})$
- The astronomical forcing was too large by about 11% and there was no SAL
- SAL omissions are known to cause large phase errors (Hendershott 1972, Gordeev et al. 1977)

Preliminary comparison, surface kinetic energy, models vs. drifters



Drifter data from the Global Drifter Program, hourly product of velocity and position, reference Elipot et al. 2016, available at http://www.aoml.noaa.gov/phod/gdp/hourly_data.php

Results sent last night by undergraduate summer intern Jonathan Brasch

Builds upon in-press paper by Yu, Ponte, Elipot, Menemenlis, Zaron, Abernathy (thanks to all of them!), which only included MITgcm.

Low/high frequency division seems problematic to me. Also, HYCOM time series is only 3 months and we've only examined 1/9th of the points.

HYCOM closer than MITgcm to drifter data in diurnal, semi-diurnal, and near-inertial bands

Summary

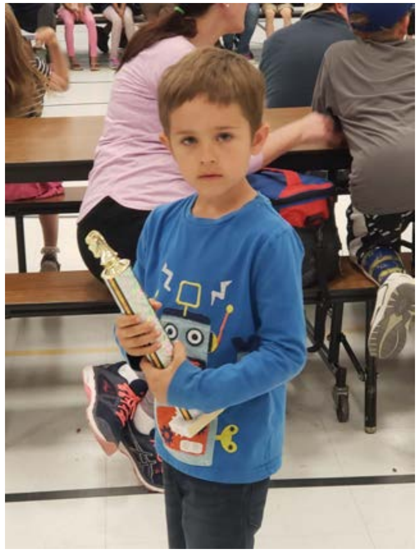
- Comparisons of global- and basin-scale HYCOM and MITgcm simulations with observations are ongoing.
- New global- and basin-scale NEMO simulations are also ready to be compared to observations.
- New comparisons shown here indicate that
  - HYCOM has a higher spatial correlation with observations than MITgcm
  - MITgcm, MOM6, HYCOM, NEMO internal tides run without extra damping such as topographic wave drag are larger than in altimetry; differences between “no wave drag” runs likely due to numerics
  - Preliminary HYCOM comparison to surface drifters indicates closer agreement than MITgcm in high-frequency bands
- Nelson et al. HYCOM result, shown last year and also today by Julien and Ed:
  - Models with concurrent atmospheric and tidal forcing can predict the geography of non-stationary internal tides relatively well.
  - Suggested grand challenge: test the ability of HYCOM/NEMO/MITgcm to accurately phase-predict non-stationary internal tides?
- Another suggestion often brought up: should the project invest in several moorings placed around the global ocean to validate both empirical and hydrodynamic global internal tide/wave models?

Winter 2019 Family Leave

Being a better, more involved uncle is a very high priority for me right now

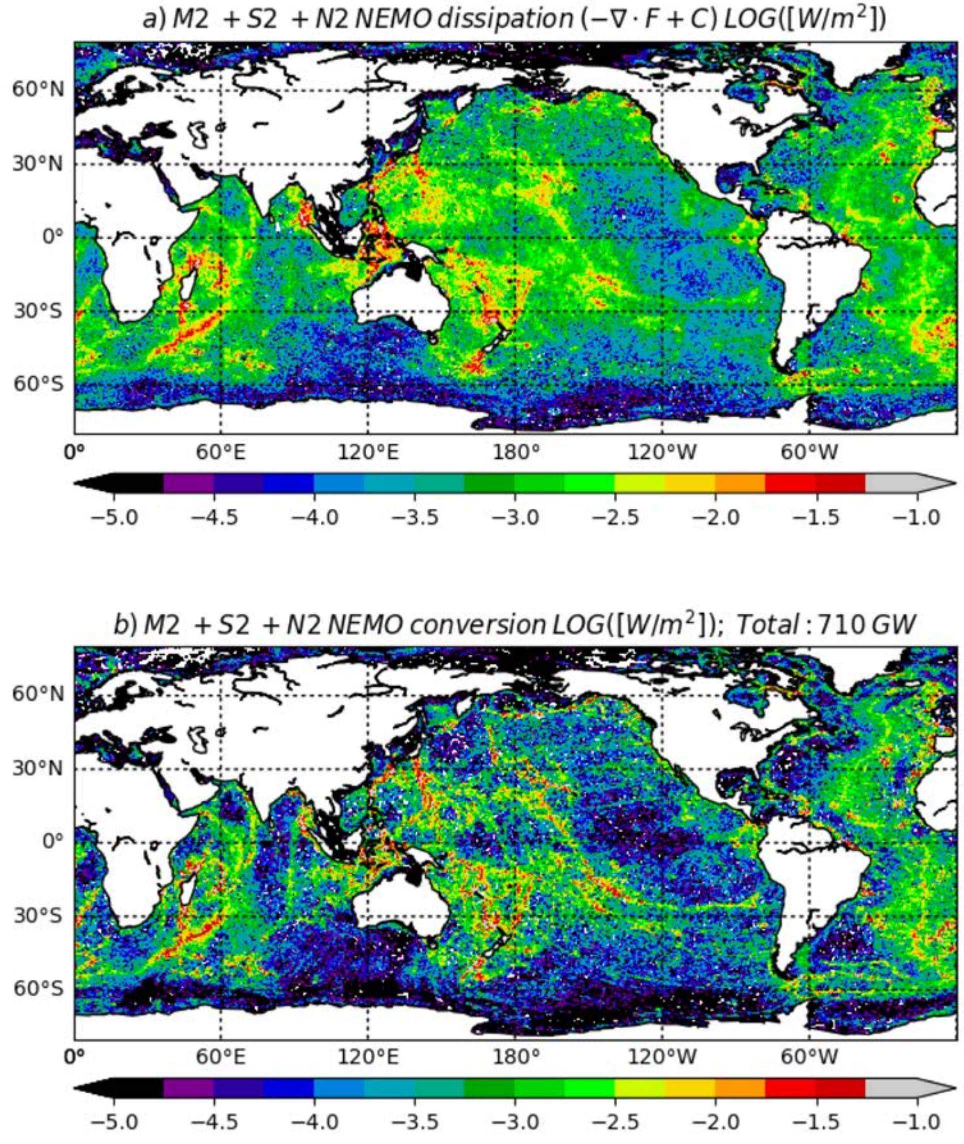
Welcome sign for long stay in Phoenix, Feb-Apr 2019

Remy 4th birthday

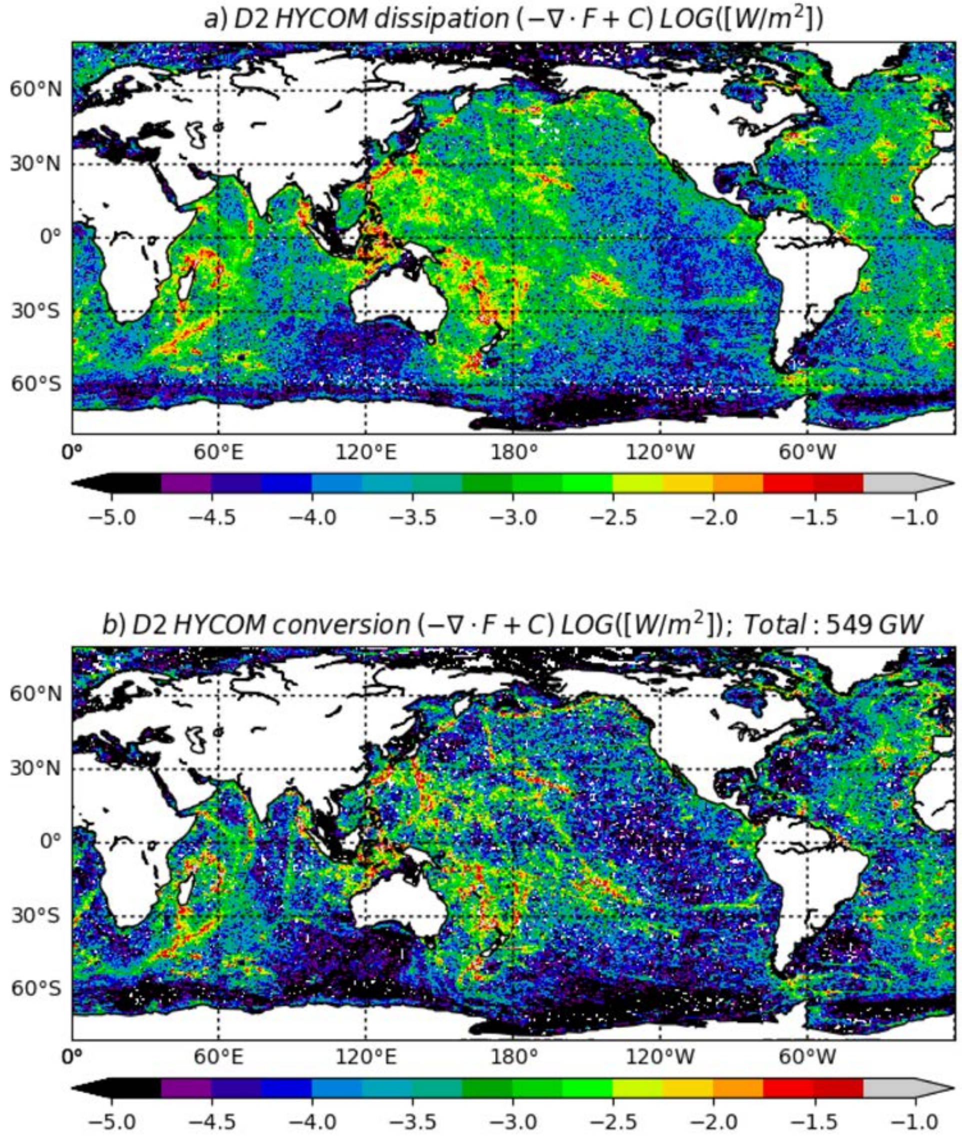


Rowan's chess trophy ←

Horse-riding in Arizona



NEMO 1/12°: 710 GW



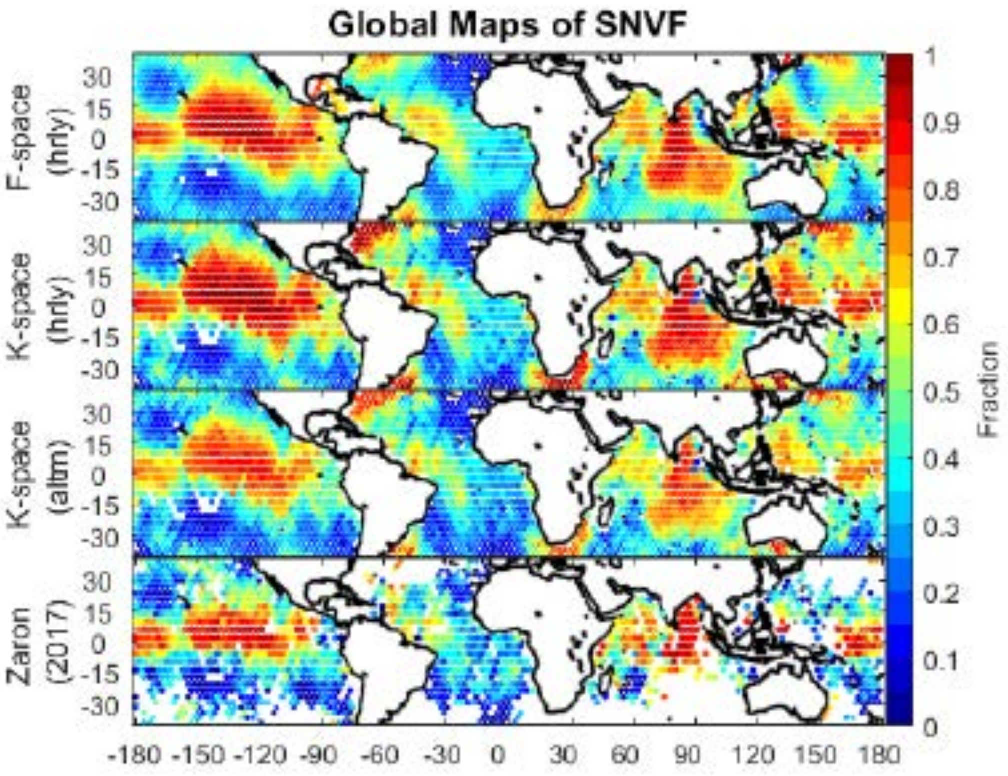
HYCOM 1/12.5°: 549 GW

More pros and cons of HYCOM

- Pros:
  - tuned wave drag
  - data assimilative-techniques acting on both eddies and tides

- Cons:
  - IGW continuum spectrum too weak relative to observations and MITgcm
  - numerical instability in high-latitude North Pacific

Semi-diurnal nonstationary variance fraction (SNVF) in HYCOM vs. altimetry (Nelson et al., in review)



Large nonstationarity in equatorial regions consistent with results of Buijsman et al. (2017)

CHAPTER 13

A Primer on Global Internal Tide and Internal Gravity Wave Continuum Modeling in HYCOM and MITgcm

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In recent years, high-resolution ("eddying") global three-dimensional ocean general circulation models have begun to include astronomical tidal forcing alongside atmospheric forcing. Such models can carry an internal tide field with a realistic amount of nonstationarity, and an internal gravity wave continuum spectrum that compares more closely with observations as model resolution increases. Global internal tide and gravity wave models are important for understanding the three-dimensional geography of ocean mixing, for operational oceanography, and for simulating and interpreting satellite altimeter observations. Here we describe the most important technical details behind such models, including atmospheric forcing, bathymetry, astronomical tidal forcing, self-attraction and loading, quadratic bottom boundary layer drag, parameterized topographic internal wave drag, shallow-water tidal equations, and a brief summary of the theory of linear internal gravity waves. We focus on simulations run with two models, the HYbrid Coordinate Ocean Model (HYCOM) and the Massachusetts Institute of Technology general circulation model (MITgcm). We compare the modeled internal tides and internal gravity wave continuum to satellite altimeter observations, moored observational records, and the predictions of the Garrett-Munk (1975) internal gravity wave continuum spectrum. We briefly examine specific topics of interest, such as tidal energetics, internal tide nonstationarity, and the role of nonlinearities in generating the modeled internal gravity wave continuum. We also describe our first attempts at using a Kalman filter to improve the accuracy of tides embedded within a general circulation model. We discuss the challenges and opportunities of modeling stationary internal tides, non-stationary internal tides, and the internal gravity wave continuum spectrum for satellite altimetry and other applications.

Arbic, B.K., et al., 2018: A primer on global internal tide and internal gravity wave continuum modeling in HYCOM and MITgcm. In "*New Frontiers in Operational Oceanography*", E. Chassignet, A. Pascual, J. Tintoré, and J. Verron, Eds., GODAE OceanView, 307-392, doi:10.17125/gov2018.ch13.

Brief history of **global- and basin-scale** internal tide and gravity wave models

- 2001, 2004: First basin- and global-scale internal tide models (Niwa and Hibiya 2001, Arbic et al. 2004, Simmons et al. 2004)
  - No atmospheric forcing
  - Idealized stratification
- 2010: First high-resolution model with concurrent tidal and atmospheric forcing (HYCOM; Arbic et al. 2010)
  - Allows for modeling of non-stationary internal tides (e.g., Shriver et al. 2014, Nelson et al. in press, others)
  - Allows for modeling of internal gravity wave (IGW) continuum spectrum (e.g., Müller et al. 2015, Savage et al. 2017a,b, others)
- 2016: Run with higher vertical and horizontal resolution (MITgcm; Rocha et al. 2016)
  - More developed IGW continuum (Savage et al. 2017b, more coming)
- New model runs in France: NEMO being run globally (1/12°; Toulouse) and over North Atlantic (1/60°; Grenoble)

Motivation for global- / basin-scale internal tide and gravity wave models

- Mixing
- Acoustics
- SWOT
  - Internal tides and high-frequency IGW continuum spectrum have a significant SSH signal at smallest scales to be measured by SWOT
- Velocity missions (S-MODE, SKIM, WACM)
  - Near-inertial motions also important

Model-data comparisons done thus far

- Important to know how “reasonable” these models are

- Comparisons have been done in about ~20 papers using HYCOM, a smaller number of papers using MITgcm. Example (not exhaustive) comparisons include:
  - SSH vs. tide gauges
  - Barotropic tide SSH vs. altimeter-constrained models
  - Internal tide SSH vs. along-track altimetry
  - Tidal currents vs. historical mooring database
  - IGW continuum KE and dynamic height variance spectra vs. historical and McLane profiler moorings
  - Wavenumber spectrum vs. shipboard along-track ACDP
  - In-press, presented by Arin Nelson last year: Non-stationary internal tides vs. altimetry
  - New: Surface kinetic energy vs. drifters