Towards an internal wave spectrum in global ocean models

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- University of Michigan: Joseph Ansong, Steve Bassette, Conrad Luecke, Anna Savage, David Trossman

- Bangor University: Patrick Timko

- Norwegian Meteorological Institute: Malte Müller

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- Florida State University: Eric Chassignet

- Others including many members of the NSF-funded Climate Process Team led by Jennifer MacKinnon of Scripps

Motivation

• In the 1990s modelers began to resolve mesoscale eddies on basin- and global-scales.

• A new frontier is global modeling of the internal wave spectrum.

• Global modeling of internal tides first done in 2004 Arbic et al. and Simmons et al. papers utilizing Hallberg Isopycnal Model (HIM)–for simplicity, these early tide-only simulations employed a horizontally uniform stratification.

• We have been developing simulations of the HYbrid Coordinate Ocean Model (HYCOM) with both atmospheric and tidal forcing, so that both near-inertial waves and tides are put into a model with a realistically varying background stratification.

• Other groups are following suit (Harper Simmons, personal communication; Dimitris Menemenlis, personal communication; Müller et al. 2012).

• Here we focus on several different model-data comparisons, AND...

Tides and altimetry

- Satellite altimetry has provided highly accurate barotropic tide models.
- Tides must be removed to a high level of accuracy before non-tidal motions can be studied in altimeter data.
- Because SWOT will measure sea surface height at small scales, SWOT mission requires accurate removal of internal tides.
- TOPEX/JASON and SWOT orbit times–9.9 and 21 days–alias high-frequency tidal motions into the mesoscale continuum.
- Aliased tides can be backed out of altimeter records only to the extent that the signal-to-noise ratio is large and the tides are stationary–both of which hold less well for internal than barotropic tides.
- Because HYCOM output is hourly, we can easily separate tidal and low-frequency motions, and play "sampling games" for altimeter missions.

HYCOM comparisons with in-situ data

–3-D tidal velocity fields in HYCOM vs. global current meter archive (Timko et al. 2012, 2013)

–internal wave kinetic energy frequency spectra in HYCOM vs. global current meter archive (Müller et al. in preparation)

–temperature variance in HYCOM vs. moored historical records (Bassette et al. and Luecke et al. in preparation)

–sea surface height (SSH) frequency spectra in HYCOM vs. global tide gauge archive (Savage et al. in revision)

Tidal kinetic energy vertical structure–averaged over thousands of current meter locations in Rob Scott's archive (Timko et al. 2013)

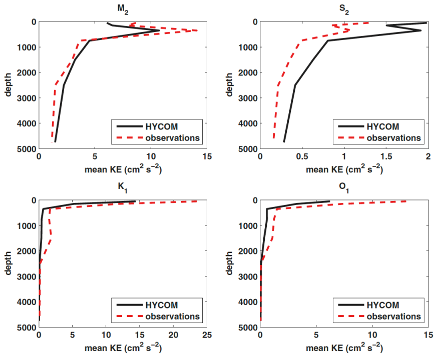
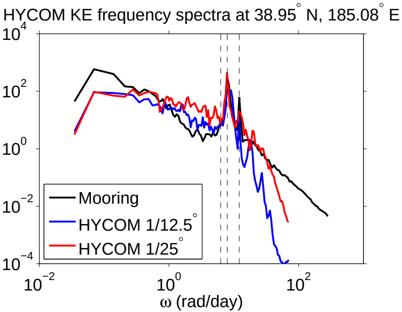
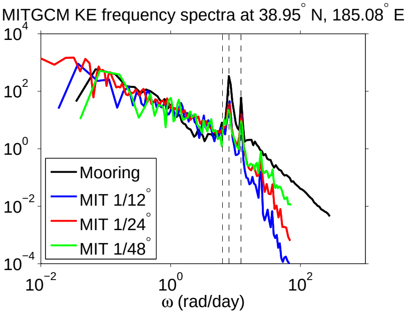


Figure 5. Vertical profiles of the average HYCOM and observed tidal kinetic energy averaged over seven depth bins for the global ocean in deep water (water column depth greater than 1000 m).

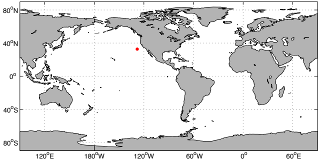
Frequency spectra of HYCOM kinetic energy (Müller et al. in preparation)

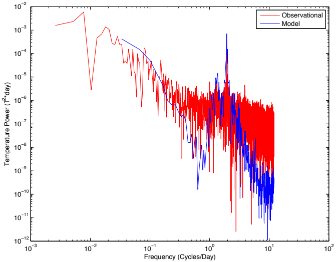


PRELIMINARY frequency spectra of MITGCM kinetic energy (thanks to Clement Ubelmann, Dimitris Menemenlis and MITgcm/ECCO collaborators)



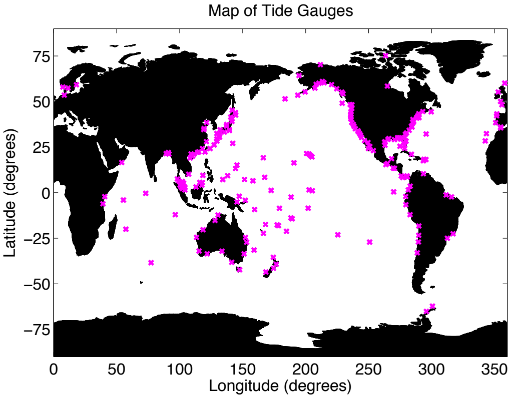
Frequency spectra of temperature (Bassette et al. and Luecke et al. in preparation)



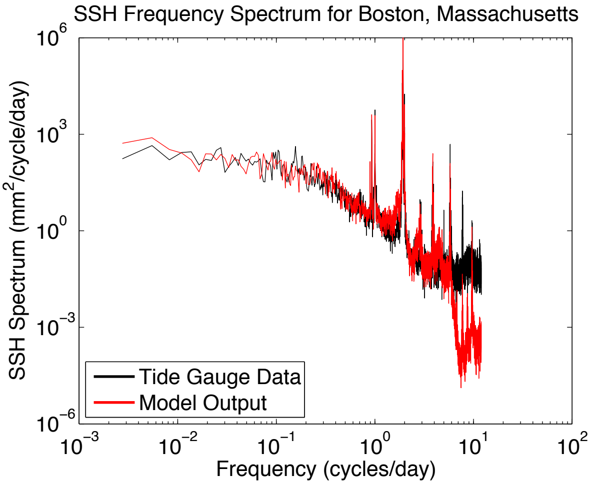


Frequency spectra of sea surface height in tide gauges versus HYCOM (Savage et al. in revision)

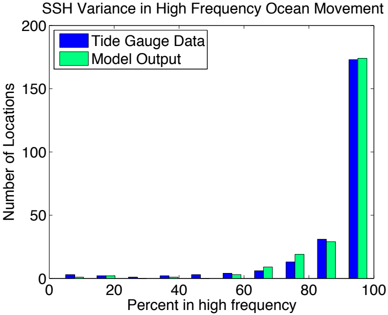
- Map of tide gauges used; 3 years continuous hourly data (U-Hawai'i Sea Level Center)



Frequency spectra of sea surface height (Savage et al. in revision)



Frequency spectra of sea surface height (Savage et al. in revision)



HYCOM comparisons with satellite altimeter data

–comparison of barotropic tide SSH signature in HYCOM vs global altimeter-constrained model (Shriver et al. 2012)

–comparison of internal tide SSH signature in HYCOM vs global along-track altimeter data (Shriver et al. 2012)

HYCOM vs TPXO M_2 barotropic tides (Shriver et al. 2012)

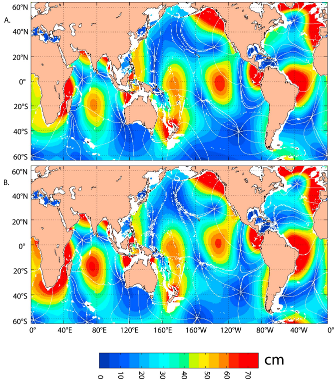


Figure 2. Amplitude (cm) of M_2 surface tidal elevation in (a) TPXO7.2 (an update to that described by *Egbert et al.* [1994]), a barotropic tide model constrained by satellite altimetry, and (b) HYCOM simulations in which the tide is unconstrained by satellite altimetry. Lines of constant phase plotted every 45° in Figures 2a and 2b are overlaid in white.

altimetry-constrained barotropic tide model [*Egbert et al.*, 1994] and the internal tides in HYCOM to results from an analysis of along-track satellite altimetry data [*Ray and Mitchum*, 1996]. Several previous comparisons of modeled and observed internal tides have utilized regional models of strong internal tide generation sites forced by specified barotropic tides at their horizontal boundaries [e.g., *Cummins et al.*, 2001; *Kang et al.*, 2000; *Merrifield et al.*, 2001].

HYCOM vs along-track altimetric estimates of surface signature of M_2 internal tides (Shriver et al. 2012)

- Computed from high-passing total M_2 signal

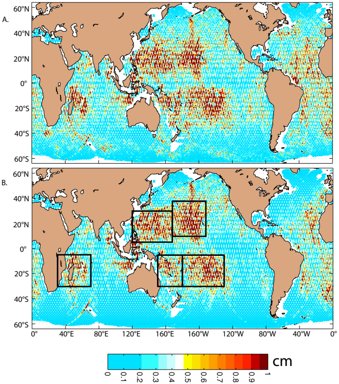


Figure 7. The M_2 internal tide amplitude from the (a) altimetric-based and (b) HYCOM tidal analyses. The five subregions denoted by black boxes in (b) are used to compute the area-averaged amplitudes in Table 2.

HYCOM vs along-track altimetric estimates of surface signature of K_1 internal tides (Shriver et al. 2012)

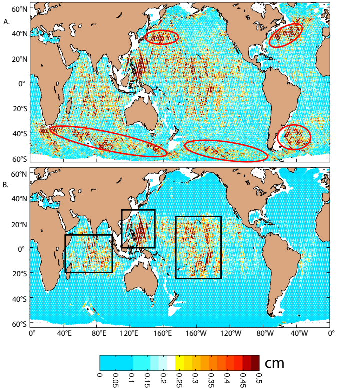


Figure 8. The K_1 internal tide amplitude from the (a) altimetric-based and (b) HYCOM tidal analyses. Areas where mesocale variability contaminates the altimetric-based tidal analysis are identified by the red circles in (a). The three subregions denoted by black boxes in (b) are used to compute the area-averaged amplitudes in Table 3.

Altimeter-centered sampling exercises with HYCOM

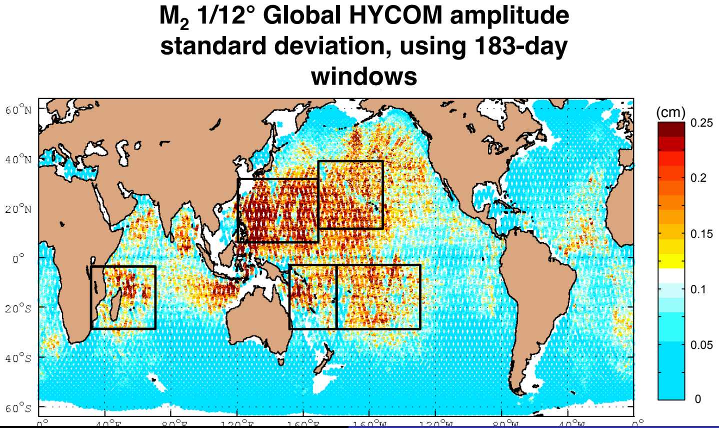
–internal tide stationarity (Shriver et al. 2014)

–errors in tidal corrections and low-frequency SSH wavenumber spectrum estimated with HYCOM sampling exercises (Savage et al. in preparation)

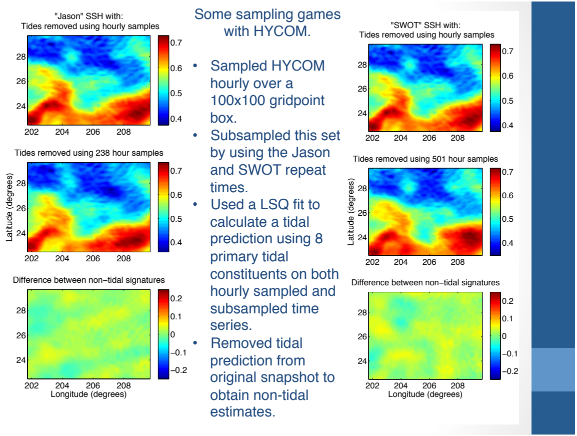
–low- vs. high-frequency contributions to SSH wavenumber spectrum (Richman et al. 2012)

Internal tide stationarity (Shriver et al. 2014)

- Non-stationarity increases to $\sim$ 1 cm when 30-day windows are used.

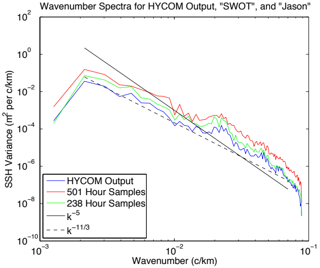


Preliminary look at tidal correction errors (Savage et al. in preparation)



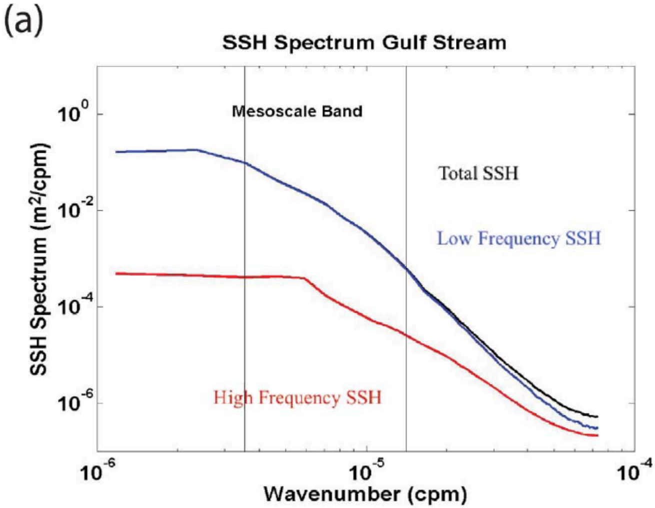
Preliminary look at errors in low-frequency SSH wavenumber spectrum (Savage et al. in preparation)

Effect on Wavenumber Spectra



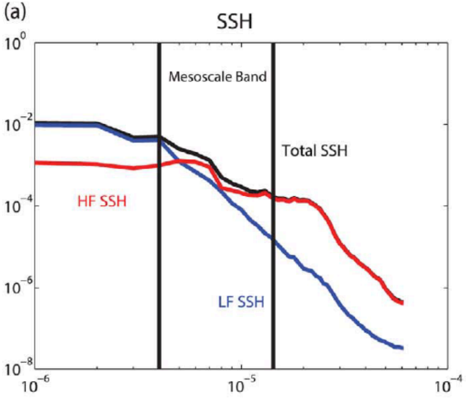
Using subsampled time series from HYCOM to simulate 'aliased' time series, the wavenumber spectra calculated for non-tidal SSH signatures is overestimated in the 'aliased' results. Theoretical "interior QG" and "SQG" results of -5 and -11/3 are shown.

Impact of internal tides on wavenumber spectrum of sea surface height (Richman et al. 2012)

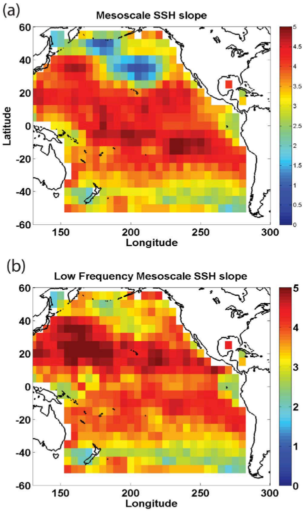


Impact of internal tides on wavenumber spectrum of sea surface height (Richman et al. 2012)

- SSH spectrum North of Hawai'i



Impact of internal tides on wavenumber spectrum of sea surface height (Richman et al. 2012)



Some other results

–parametric subharmonic instability (Ansong et al. in revision)

Parametric Subharmonic Instability (PSI) at critical latitudes (Ansong et al. in revision)

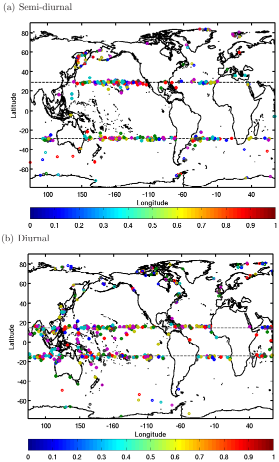


FIG. 4. Global distribution of PSI from the (*a*) semi-diurnal and (*b*) diurnal bands. The plots show significant bicoherence values at each grid location from the baroclinic velocities obtained from layer 14 ($\approx$ 500 m depth) of the model. In each case the energy in the subharmonic signals is at least 1 % of that of the primary waves.

Summary

• Just as models began to develop a realistic field of mesoscale eddies in the 1990s, models are now beginning to develop a spectrum of internal waves.

• As an example, concurrent simulation of tides and eddying general circulation achieved in global HYCOM.

• HYCOM internal waves (especially tides) are being used in a variety of studies, including many comparisons against in-situ and altimeter observational products.

• HYCOM results useful for SWOT mission planning.