Nonlinear interactions in frequency-wavenumber space diagnosed from eddying ocean model simulations with embedded tides

Brian K. Arbic

Department of Earth and Environmental Sciences
University of Michigan

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Collaborators

- Naval Research Laboratory Stennis Space Center: Maarten Buijsman, Joe Metzger, Jim Richman, Jay Shriver, Alan Wallcraft, Luis Zamudio

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

- Bangor University: Patrick Timko

- Norwegian Meteorological Institute: Malte Müller

- University of Brest and The University of Texas at Austin: Rob Scott

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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

Outline

• Brief overview of motivation for and implementation of tides in HYCOM

• Brief overview of some scientific applications, including applications to altimeter design

–Shriver et al. 2012: Comparison of internal tide signature at sea surface in model vs along-track altimeter data

–Richman et al. 2012: Impact of internal waves on sea surface height (SSH) wavenumber spectra

–Shriver et al. in prep: Internal tide stationarity

–Müller et al. in prep: Internal wave kinetic energy frequency spectra and nonlinear interactions

Motivation

• Ocean mixing driven partly by breaking internal gravity waves, which source partly from tides. First global models of internal tides, run with Hallberg Isopycnal Model (Arbic et al. 2004, Simmons et al. 2004), included only tidal forcing and were run with horizontally uniform stratification.

• Desirable to have model in which generation and propagation of internal (baroclinic) tides takes place in more realistic, horizontally varying stratification, and potential exists for interactions between tidal and non-tidal flows.

• Recent simulations have accomplished this: several multi-year global runs of HYbrid Coordinate Ocean Model (HYCOM) with 32 layers in the vertical direction, $1/12.5^\circ$ and $1/25^\circ$ horizontal resolution, and astronomical tidal potential forcing in addition to wind- and buoyancy-forcing.

• Realistic environment to study many interesting scientific and operational questions.

Implementation and technical challenges

- Astronomical tidal potential
- Self-attraction and loading
- Topographic wave drag

Implementation of astronomical tidal potential

• To illustrate how tidal potential is implemented in an ocean model, we show the one-layer shallow-water momentum equations with tidal forcing:

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \bullet \nabla \vec{u} + f\hat{k} \times \vec{u} = -g\nabla(\eta - \eta_{EQ} - \eta_{SAL}) + \mathit{Friction}$$

• Symbols above are standard. We will shortly discuss:

–Astronomical tidal potential η_{EQ}

–Self-attraction and loading term η_{SAL}

Astronomical tidal potential

• Equilibrium tide for one semidiurnal tidal constituent is

$$\eta_{EQ} = A(1 + k_2 - h_2)cos^2(\phi)cos(\omega t + 2\lambda),$$

where A is amplitude, ϕ is latitude, ω is frequency, t is time, λ is longitude

• Love numbers h_2 and k_2 account for seafloor deformation and gravitational potential perturbation arising from solid earth body tides.

Self-attraction and loading

• Solid-earth load deformation, impacts of self-gravitation of deformed earth (and ocean itself) on gravitational potential known as self-attraction and loading (SAL) term (Hendershott 1972).

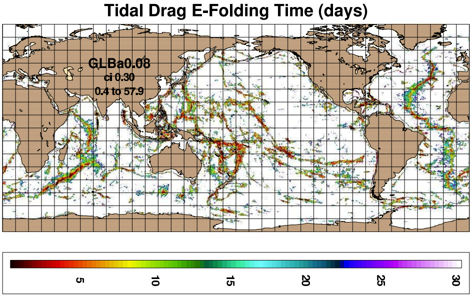
$$\eta_{SAL} = \sum_n (1 + k_n' - h_n') \frac{3\rho_{water}}{\rho_{earth}(2n+1)} \eta_n$$

• Challenging to implement because spherical harmonics η_n are computationally expensive.

• Currently using "scalar approximation" $\eta_{SAL} \approx 0.06\eta$

• Better methods on the way.

Topographic wave drag e-folding time in first run (Arbic Wallcraft Metzger 2010)

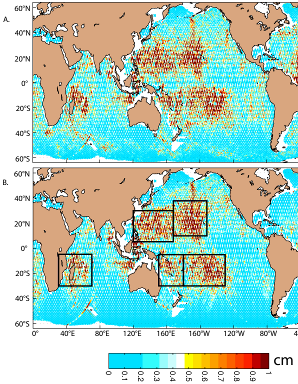


New complication for topographic drag in HYCOM wind-plus-tides simulation

- Topographic wave drag probably acts on low-frequency motions (Nikurashin and Ferrari 2011; Scott et al. 2011; Wright et al. in review; Trossman et al. in review) as well as tides.
- But the action is different for the two types of motions (Bell 1975).
- Therefore, a separation of the model bottom flows into tidal versus non-tidal components is desirable.
- This separation is done with a filter on the bottom flow running in the time domain.
- Must be implemented carefully to avoid numerical problems.

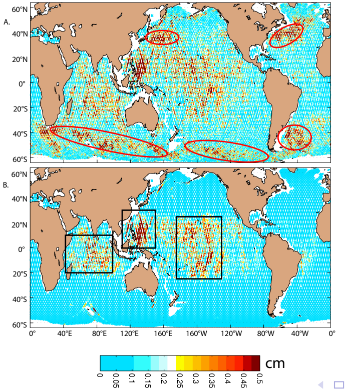
HYCOM vs along-track altimetric estimates of surface signature of M_2 internal tides (Shriver et al. 2012)

- Computed from high-passing total M_2 signal
- TOP/BOTTOM: along-track altimetry/HYCOM

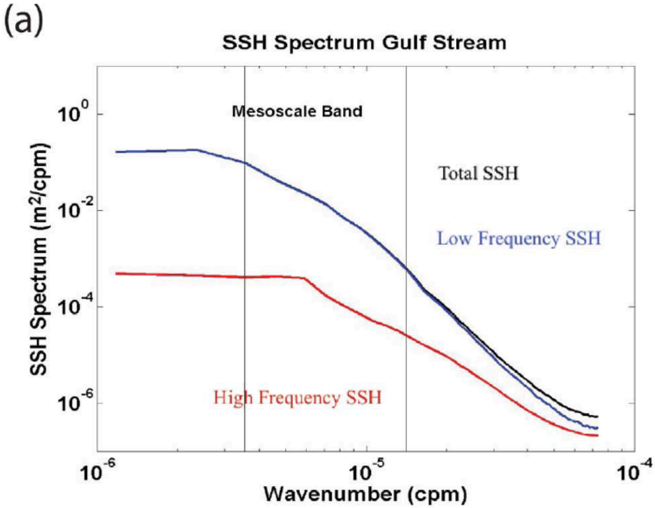


HYCOM vs along-track altimetric estimates of surface signature of K_1 internal tides (Shriver et al. 2012)

- Computed from high-passing total K_1 signal
- TOP/BOTTOM: along-track altimetry/HYCOM

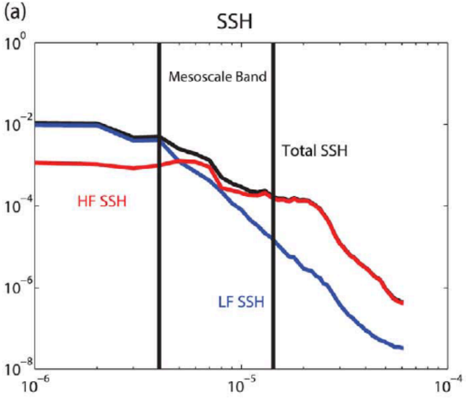


Impact of internal tides on wavenumber spectrum of sea surface height (Richman et al. 2012)

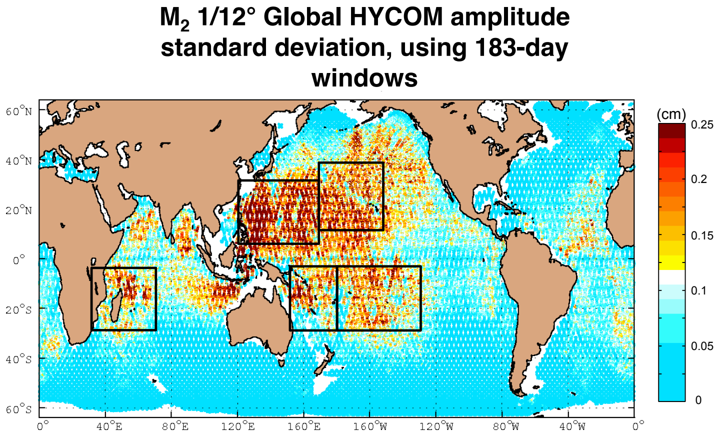


Impact of internal tides on wavenumber spectrum of sea surface height (Richman et al. 2012)

- SSH spectrum North of Hawai'i

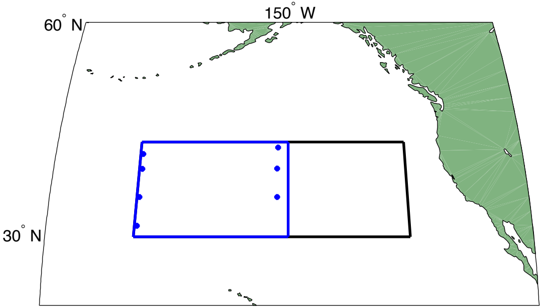


Internal tide stationarity (Shriver et al., in preparation)



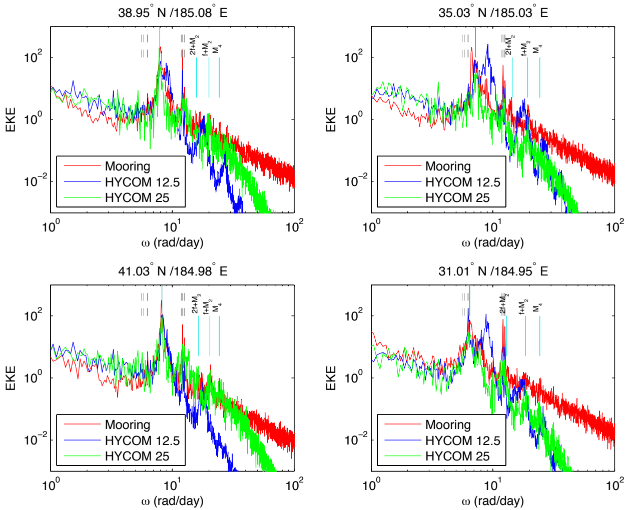
Internal wave kinetic energy frequency spectra and nonlinear interactions (Müller et al., in prep)

- Region examined and mooring locations



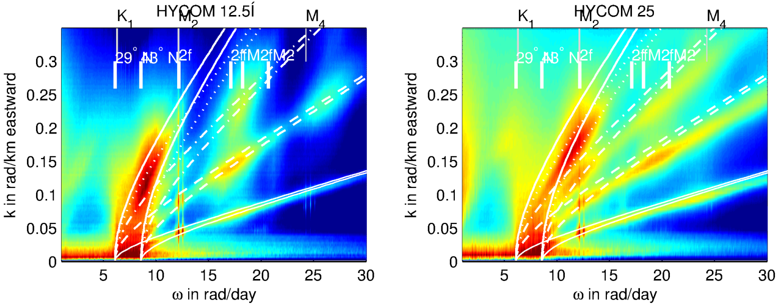
Internal wave kinetic energy frequency spectra and nonlinear interactions (Müller et al., in prep)

- Frequency spectra



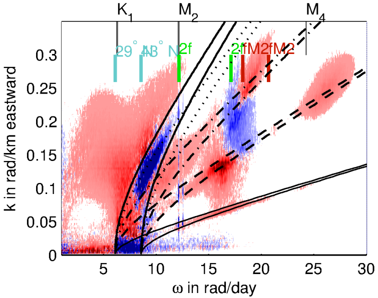
Internal wave kinetic energy frequency spectra and nonlinear interactions (Müller et al., in prep)

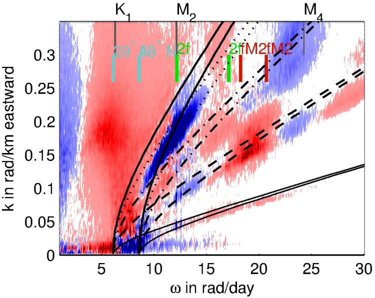
- Frequency-wavenumber spectra



Internal wave kinetic energy frequency spectra and nonlinear interactions (Müller et al., in prep)

- Frequency-wavenumber spectral transfers
- $1/12.5^{\circ}$ on left, $1/25^{\circ}$ on right





Summary

• Concurrent simulation of tides and eddying general circulation achieved in global HYCOM.

• HYCOM simulations represent considerable improvement over first global baroclinic tide simulations; horizontally varying stratification, much more validation work performed.

• HYCOM with tides simulations already being used, or will be used, in a host of operational and scientific studies.