Numerical investigation of nonlinear internal wave generation and breaking in straits

Principal Investigator information

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Research interests

We propose to examine the generation of internal waves by tidal flow through the straits that separate the open ocean from the Western Pacific basins, using nonhydrostatic simulations with the MITgcm in both 2 and 3-dimensions, and working with observationalists involved in the DRI to ensure tidal forcing, stratification and topography correspond to observed values. The MITgcm is well-suited for this work, having been used extensively to study internal tide generation and breaking processes (Legg and Adcroft, 2003; Legg, 2004a,b; Legg and Huijts, 2006; Green et al., 2008; Legg and Klymak, 2008) (as well as several studies by other authors). The model can be configured for forcing either through imposed oscillatory flow at the boundaries, or through a body-forcing term. Radiative boundary conditions applied to the baroclinic component of flow allow internal waves to pass out of the model domain with no reflection (Khatiwala, 2003). The finite volume algorithm allows arbitrary topography to be represented (Adcroft et al., 1997).

The focus of the study will be the character of the internal waves generated by the tidal flow (e.g. their nonlinearity, amplitude, wavelength and frequency) and the possibilities for modification of these characteristics by local breaking in the generation region. Ultimately the nature of the waves in the basins depends not only on the initially generated waves, but also on any breaking that may have taken place prior to propagation into the basin interior.

A particular focus will be a study of the factors that influence the horizontal and vertical scales of the resultant internal tides. For linear waves generated over shallow topography, it is now well-understood that the topography sets the horizontal length-scale of the wave (Bell, 1975), while for steep, but small amplitude topography (compared to the full ocean depth) the internal wave response takes the form of a narrow beam (Llewellyn Smith and Young, 2003). However, for tall, steep topography, such as that found in the study area, the length scales of the response are complicated, containing both large and small scales (St Laurent et al., 2003). Recent studies (Legg and Klymak, 2008) have also shown that for tall topography, the smallest energy-containing scales may be subject to transient hydraulic control, and so be arrested. On relaxation of the tide, the arrested waves may break at the topography and hence lose their energy to dissipation. The key question is therefore, how do the details of the topography and stratification determine (a) the initial energy-containing scales; (b) the energy-containing scales away from the topography?

Earlier studies (Legg and Klymak, 2008) have focused on the nonlinear wave processes near the topography. When such nonlinear waves propagate toward the topography on relaxation of the tidal flow, they may break on the topographic slope on reflection. However, depending on the local stratification, nonlinear waves may be generated at some height above the topography, where they are less liable to break locally on the topography. We will examine how the process of local wave breaking, and subsequent character of the propagating wave, depend on the vertical profile of stratification. This is particularly important in considering the effect of atmospheric conditions on the internal tide generation process, since it is through the surface mixed layer stratification that atmospheric forcing is communicated to the ocean. Through this study we will obtain an understanding of seasonal and subseasonal modulation expected in the internal tide field.

We intend to work closely with the observationalists involved in this program to interpret observed phenomena through the use of numerical simulation. This methodology has been followed in Legg's earlier studies, e.g. for the Littoral Internal Waves Initiative (Legg, 2004a,b), collaborating with Kurt Polzin, and for the Hawaiian Ocean Mixing Experiment (Legg and Klymak, 2008), collaborating with Jody Klymak. When the observational elements of the program become clearer, i.e. at the proposal writing stage, we will provide more detail as to the exact nature of the observational/numerical collaboration. We anticipate that for observational elements focused on nonlinear features in the straits, we will aid in the experiment design by exploring the possible nonlinear features numerically for particular straits.

A key technical aspect of this study will be to compare simulations using the MITgcm, with and without the nonhydrostatic solver enabled. Earlier studies have indicated that the nonhydrostatic dynamics may be an important component of the development of internal solitary waves. Here we will explore the degree to which the nonhydrostatic dynamics is essential to be able to capture the correct length-scales and energetics of the generation site. For example it is possible that without nonhydrostatic dynamics, the local breaking of the nonlinear waves would not occur correctly. This may then affect the wave-length spectrum of the radiating waves. To complement this study using MITgcm, we will also use GOLD (Generalized Ocean Layer Dynamics), the current GFDL isopycnal model descended from HIM (Hallberg Isopycnal Model) to carry out identical simulations with a layered hydrostatic model, very similar to HYCOM. We will examine whether the gross features of the flow may be correctly captured in the layered model by including scale-selective dissipation and localized mixing at the ridges. We expect that advances made in the representation of these processes in GOLD will be easily transferred to HYCOM.

This study will be performed with simulations of increasing complexity, beginning with 2-dimensional simulations with horizontally uniform stratification, proceeding to horizontally varying stratification (and associated geostrophic currents), and then including 3-dimensions with topography that varies in both horizontal directions. Of course computational limitations will mean that much of the parameter space investigations are done in 2-dimensions, while a small number of 3 -dimensional studies will be reserved for examination of the effects of complex realistic topography.

To summarize the goals of this study are:

- An evaluation of the impact of topographic shape and stratification on the lengthscales and amplitude of the internal wave response to tidal forcing through straits.
- An understanding of the impact of seasonal variations in stratification and/or geostrophic currents on the lengthscales and amplitude of the internal tides.
- An examination of the dependence of nonlinear features and local breaking at the generation site on topography and stratification.

- An evaluation of the relative ability of nonhydrostatic and hydrostatic models (both z-coordinate and layered) to represent these features.

References

Adcroft, A., Hill, C., Marshall, J., 1997. Represention of Topography by Shaved Cells in a Height Coordinate Ocean Model. Mon. Wea. Rev. 125, 2293–2315.

Bell, T., 1975. Topographically generated internal waves in the open ocean. J. Geophys. Res. 80, 320–327.

Green, J., Simpson, J., Legg, S., Palmer, M., 2008. Internal waves, baroclinic energy fluxes and mixing at the European shelf edge. Cont. Shelf Res. 28, 937–950.

Khatiwala, S., 2003. Generation of internal tides in an ocean of finite depth: analytical and numerical calculations. Deep Sea Res. 50, 3–21.

Legg, S., 2004a. Internal tides generated on a corrugated continental slope. Part I: Cross-slope barotropic forcing. J. Phys. Oceanogr. 34, 156–173.

Legg, S., 2004b. Internal tides generated on a corrugated continental slope. Part II: Along-slope barotropic forcing. J. Phys. Oceanogr. 34, 1824–1834.

Legg, S., Adcroft, A., 2003. Internal wave breaking at concave and convex continental slopes. J. Phys. Oceanogr. 33, 2224–2246.

Legg, S., Huijts, K., 2006. Preliminary simulations of internal waves and mixing generated by finite amplitude tidal flow over isolated topography. Deep Sea Research, Part II 53, 140–156.

Legg, S., Klymak, J., 2008. Internal hydraulic jumps and overturning generated by tidal flow over a tall steep ridge. J. Phys. Oceanogr., in press.

Llewellyn Smith, S., Young, W., 2003. Tidal conversion at a very steep ridge. J. Fluid. Mech. 495, 175–191.

St Laurent, L., Stringer, S., Garrett, C., Perrault-Joncas, D., 2003. The generation of internal tides at abrupt topography. Deep Sea Res. 50, 987–1003.

Proposed budget

We are requesting salary funds for 1 month per year for Legg for 3 years, and 12 months per year for a Princeton University postdoctoral researcher for 2 years, beginning in the second year of the program. This delay in the start date of the postdoc will allow time to identify a good candidate, and allow for the program to spin up before the postdoc begins, therefore maximizing the use of the postdoc's time. The bulk of the work will be done by the postdoc, but the senior PI will plan the initial series of simulations, provide guidance for the configuration of the model, and assist the postdoc in technical and scientific interpretation. We are requesting a $ 3000 laptop for the postdoc, as well as funds for other materials and services at $ 500 per year. We are requesting funds for travel as follows: 1 trip per year for Legg to attend workshops associated with the DRI, 1 trip per year for the postdoc to attend conferences and/or workshops. Finally we request funds for publications in years 2 and 3. The requested totals are therefore as follows:

budget item	2009	2010	2011	total
faculty salary	$8,796	$9,148	$9,514	$27,458
Postdoc salary	0	$50,000	$53,000	$103,000
Materials and services	$500	$3500	$500	$4500
Publications	0	$3000	$3000	$6000
Travel domestic	$1500	$3500	$3500	$8500
Benefits	$3,048	$20,673	$22,132	$45,853
Overhead	$4153	$26,946	$27,494	$58,593
total	$17,997	$116,767	$119,139	$253,903

Resume: Sonya Allayne Legg

Education: Oxford University, Physics BA Honors, 1989; Imperial College, University of London, Physical Oceanography PhD, 1993.

Appointments: Research Oceanographer, Princeton University, 2004-present; Associate Scientist, Woods Hole Oceanographic Institution, 2001-2006 (awarded tenure 2005); Assistant Scientist, Woods Hole Oceanographic Institution, 1997-2001; Assistant Researcher, UCLA, 1997; NOAA Climate and Global Change postdoctoral fellow, 1995-1997; Postdoctoral research associate, University of Colorado, 1993-1995; Research fellow, MIT, 1991-1992.

Recent publications († indicates publications most relevant to proposed research)

† Legg S. and A. J. Adcroft, 2003. Internal wave breaking on concave and convex continental slopes, *J. Phys Oceanogr.* **33**, 2224-2246.

† Legg S., 2004. Internal tides generated on a corrugated continental slope. Part I: Cross-slope barotropic forcing, *J. Phys Oceanogr.* **34**, 156-173.

† Legg S., 2004. Internal tides generated on a corrugated continental slope. Part II: Along-slope barotropic forcing, *J. Phys Oceanogr.* **34**, 1824-1838.

† Legg S. and K.M.H. Huijts, 2006. Preliminary simulations of internal waves and mixing generated by finite amplitude tidal flow over isolated topography, *Deep Sea Research, part II*, **53**, 140-156.

Legg S., R.W. Hallberg and J.B. Girton, 2006. Comparison of entrainment in overflows simulated by z-coordinate, isopycnal and nonhydrostatic models, *Ocean Modelling*, **11**, 69-97.

Riemenschneider U. and S. Legg, 2007. Regional Simulations of the Faroe Bank Channel Overflow in a Level Model, *Ocean Modelling*, **17**, 93-122.

† Green J.A.M., J.H. Simpson, S. Legg and M.R. Palmer, 2008. Internal waves, baroclinic energy fluxes and mixing at the European shelf edge, *Continental Shelf Research*, **28**, 937-950.

Jackson L., R.W. Hallberg and Legg S., 2008. A parameterization of shear-driven turbulence for ocean climate models, *J. Phys. Oceanogr.*, in press.

Legg S., L. Jackson and R.W. Hallberg, 2008. Eddy-resolving modeling of overflows, *AGU Geophysical Monograph on Eddy-resolving Ocean Modeling*, in press.

† Legg S. and J. Klymak, 2008. Internal Hydraulic Jumps and Overturning Generated by Tidal Flow over a Tall Steep Ridge, *J. Phys. Oceanogr.*, in press.

Synergistic Activities: Coordinating PI for Gravity Current Entrainment Climate Process Team, 2003-present; Associate member of IAPSO/SCOR working group 121 on Ocean Mixing, 2004-2007; Member of USCLIVAR Process Studies and Model Improvement Panel, 2005-present, co-chair of panel, 2007-present; member of faculty of Princeton University/GFDL graduate program on Atmospheric and Ocean Sciences, 2004-present.