OS51D HC: 316 B Friday 0830h

Oceanic Internal Tides IV

Presiding: **D Luther,** University of Hawaii at Manoa; **M Levine,** Oregon State University

OS51D-01 0830h

Simple Models of Internal Tide Generation at Abrupt Topography

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The general principles of internal tide generation are well-known and models of considerable complexity are being used. Nonetheless, insight may still be obtained from simple models. Here we consider models with depth discontinuities.

First, we show analytically and by comparison with exact solutions that it is not correct to approximate the internal tide generation at arbitrary 2D topography by the generation at a finite number of steps, with the internal tide generated at each assumed independent. Any reasonable results obtained with this approach must be regarded as fortuitous.

Second, we compare internal tide generation at step topography with that at a linear continental slope (Craig, *J. Mar. Res.* 1987). Craig argued that for supercritical conditions the energy flux increases like α, the ratio of bottom slope to ray slope. This clearly cannot apply when $\alpha \to \infty$, the limit corresponding to a step. We establish how steep a slope must be to be nearly equivalent to a cliff.

Third, we extend earlier studies of the internal tide generated at a knife edge, for comparison with results for a ridge with a section of supercritical slope.

OS51D-02 0845h

Tidal Conversion by Critical Topography

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We present analytical estimates of the rate at which energy is extracted from the barotropic tide at topography. This energy is radiated away from the bottom as internal gravity waves (the "internal tide"); the ocean is idealized as vertically unbounded so this radiation freely escapes to $z = +\infty$. We use two model topographies: a sinusoidal ripple and a family of profiles which approximates a periodically spaced set of Gaussian bumps. The conversion rate is expressed as a function of a parameter, ϵ, which is the ratio of the slope of an internal tidal rays to the maximum slope of the topography. The critical slope condition is $\epsilon = 1$ and most previous estimates of the conversion rate apply only if $\epsilon \ll 1$. Our results span the interval $0 \le \epsilon \le 1$. At the critical point, $\epsilon = 1$, the conversion of sinusoidal topography is 56% greater than the weak-topography ($\epsilon \ll 1$) estimate. In the Gaussian case, the enhancement at $\epsilon = 1$ is only 14% greater than the weak-topography estimate. These finite-slope enhancements are modest and we conclude that the weak-slope approximation provides quantitatively useful estimates of conversion rates.

OS51D-03 0900h

Generation of Internal Tides in the Ocean

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Mixing in the abyssal ocean is known to play an important role in controlling the large scale ocean circulation. In the search for sources of mechanical energy for mixing, internal tides generated by the interaction of the barotropic tide with bottom topography ("mode conversion") have been implicated. However, estimates of the rate at which barotropic tidal energy is converted into the internal wave field are quite uncertain. Here, we present analytical and numerical calculations of internal tide generation in a fluid layer of finite depth to better understand the energetics of the wave generation process. Previous theoretical models of wave generation have assumed an upper radiation boundary condition appropriate for an ocean of infinite depth. But recent observations of internal tides at significant distances from their generation region indicate that this boundary condition is not always valid, and that reflection from the upper surface is important. We show that the presence of an upper free-surface greatly modifies the rate at which energy is fed into the internal wave field (the power) and thus the energy available for mixing. Fully non-hydrostatic, nonlinear numerical calculations are used to both test the theory and to explore more realistic parameters for which linear theories are formally invalid.

URL: http://puddle.mit.edu/˜spk/

OS51D-04 0915h

Two Regimes of Internal Tide Generation Over Bottom Topography

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Two different regimes of internal tide generation are identified in a numerical model of barotropic tidal flows over idealized bottom topography. In the subcritical regime where bottom topography is less steep than wave rays, internal tides can be efficiently generated and radiate away from the bottom topography. The energy flux to internal tides increases with increasing topographic steepness and reaches a maximum at the critical slope. For tidal flows over supercritical bottom topography, however, strong turbulent mixing occurs in wave beams near the bottom topography. This suppresses the radiation of internal tides into the ocean interior. In the supercritical regime, the energy flux to internal tides show a rapid decrease with increasing topographic steepness, though the result may be sensitive to the subgrid-scale parameterization scheme used to calculate the mixing coefficients in the numerical model.

OS51D-05 0930h

First Mode Internal Tide Scattering From Topography

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The Princeton Ocean Model is used to examine the scattering of a first mode internal M_2 tide from idealized topography. The internal tide is specified at the western boundary and propagates eastward towards the topography, either a Gaussian ridge, trough, or seamount. Subcritical, critical, and supercritical slopes are examined. Constant and realistic stratification are used. The modal structures of the reflected and transmitted internal tide are determined.

OS51D-06 0945h

Internal Tide Generation on a Corrugated Slope

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Recent observations of mixing and tidal frequency variability on the continental slope offshore of the Southeastern USA have motivated a numerical study of the internal tides generated on a slope traversed by regularly spaced ridges and valleys (or "corrugations"). The cross-slope barotropic tide leads to the generation of an internal tide emanating primarily from the shelf-break (where the slope changes from supercritical to subcritical with respect to the internal tide characteristic slope). In the absence of corrugations this internal tide propagates off shore in the form of the gravest vertical mode after reflecting off the bottom. However, with the addition of corrugations, the reflection leads to a higher mode structure above the slope, with bands of shear extending from top to bottom. If the tidal forcing is sufficiently strong, this shear may lead to Kelvin-Helmholtz instability and mixing. This high-mode structure is completely absent if rotation is ignored, suggesting that the along-slope component of flow associated with the rotating internal wave only is responsible for this interaction with the corrugations.

The along-slope barotropic tide generates internal waves on the length-scale of the corrugations when the flow is relatively weak. When the barotropic tide is stronger, highly nonlinear features such as internal hydraulic jumps downstream of the ridges are found, with associated overturning. The relaxation of these jumps leads to the development of solitary wave packets, which propagate up into the thermocline, where they may provide a source of shear for small scale mixing. The corrugations therefore play a vital role in the generation of shear and mixing by the interaction of the barotropic tides with the continental slope.

URL: http://charybdis.whoi.edu/sonya

OS51D-07 1020h

On the Energy Balance of Internal Tides above Rough Topography

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Recent fine- and microstructure observations from the Brazil Basin indicate enhanced finescale shear and strain in conjunction with bottom intensified turbulent dissipation above regions of rough bathymetry. Such observations implicate the bottom boundary as an energy source for the finescale internal wavefield. A theoretical estimate of the dissipation profile is presented. Inputs to this estimate consist of the semi-diurnal barotropic tidal amplitude, the observed stratification and a spectral representation of the topographic roughness. The boundary conditions consist of a quasi-linear generation model of oscillatory flow over infinetesimal amplitude topography at the bottom and reflection at the upper surface. A non-linear propagation model is used to estimate the vertical profile of dissipation. This estimate agrees with observed dissipation profile to within a factor of 2.

OS51D-08 1035h

Ocean Floor Topography From Space: the ABySS Mission

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Vertical mixing is observed to increase above rough bottom topography. The cause is attributed to a variety of mechanisms with mixing regimes depending on the amplitude of topographic slopes and roughness in the direction of flow over horizontal length scales from 100 m to 100 km. Less than 0.1% of the deep ocean bottom has actually been acoustically mapped with sufficient coverage to resolve seafloor topography at these scales. Existing data suggest that at scales shorter than 10–30 km the topography is composed of self-affine abyssal hills generated by mid-ocean ridge processes, and the power spectrum has a characteristic fractal decay; however, the spectral parameters are azimuth-dependent because the hills are elongate in map view. A mixture of geologic processes shape topography at larger scales and so this part of the spectrum is less predictable, and often less red. The overall roughness and also the wavelength of transition between the fractal and non-fractal regimes both seem to be controlled by the seafloor spreading process, with spreading rate being one major factor; abyssal hills are generally higher-amplitude and longer-wavelength at slower-spreading ridges.

Unfortunately, global representations of bathymetry are artificially smooth and fail to fully resolve the length scale at which the topography transitions from heterogeneous to fractal. Estimates obtained from satellite altimeters in geodetic orbits (e.g. Smith & Sandwell, 1997) are smoothed at full-wavelengths shorter than 25–40 km in order to stabilize the inversion of seafloor topography from noisy sea surface gravity anomalies. At low latitudes these data also resolve N-S slopes more easily than E-W slopes, due to the fairly polar inclinations of the satellites' orbits. The situation is even worse in ETOPO5 and DBDB5, which were interpolated from hand-drawn contour charts, in turn based on sounding lines often hundreds of km apart; slopes and roughness in these data at 100 km and shorter scales are largely artifacts of the sparse data distribution and the various contouring styles of the individuals who drew the charts.

We have proposed a new NOAA-NASA Earth System Science Pathfinder mission, Altimetric Bathymetry from Surface Slopes (ABySS), to obtain data on ocean floor topography down to full-wavelengths as short as 12 km, beyond which the seafloor roughness spectrum may be extrapolated due to its fractal nature at short

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scales. ABySS will use the physical connection between ocean surface altimetry and sea floor topography demonstrated in previous altimeter missions, but with two key innovations that will permit resolution of the critical transition to fractal behavior. A delay Doppler altimeter will obtain lower noise levels and reduced sensitivity to wave height; the improvement in surface gravity error amplitude of about a factor of 7 will reveal the transition to fractal scales. The use of a moderate inclination non-repeat orbiter (the International Space Station) will ensure that the resolution is isotropic in azimuth while still covering more than 80% of the oceans.

URL: http://fermi.jhuapl.edu/abyss

OS51D-09 1050h

A Parameterization for Abyssal Tidal Dissipation Based on Non-radiating Drag

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We present results from a high-resolution global numerical simulation of the M2 tide, building upon the work of Jayne and St. Laurent (presented at the last Ocean Sciences meeting). Using a scheme for internal wave drag over mid-ocean rough topography, they brought simulations of tidal elevation and abyssal dissipation closer to altimetric observations. We implement a scheme that differs from theirs in two major ways. First, it is an exact solution even with arbitrary topography as long as the topography is small-amplitude. More importantly for the present application, and following an established line of meteorological research, our scheme changes form based on the nondimensional mountain height NH/U. (Here N is the Brunt-Vaisala frequency, H is the mountain height, and U is the tidal velocity). When NH/U is less than an order unity parameter, drag is proportional to tidal velocity, as in the scheme used by Jayne and St. Laurent. When this parameter is exceeded, radiating waves and linear drag occur only at the tips of seamounts, while the flow below is deflected around the seamount, leading to a non-radiating drag quadratic with the tidal velocity. For typical values of N and U in the mid-ocean, H need only exceed 20 meters for the nondimensional mountain height to exceed unity. This suggests that flow-splitting may indeed be prevelant around mid-ocean topographic features. We examine the sensitivity of our tidal simulations to parameters in the dissipation scheme, and the relative strengths of propagating and non-propagating drag.

OS51D-10 1105h

Long Internal Gravity Waves as a Factor of Large-Scale Transport

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Traditional numerical modeling efforts are focused on quasi-geostrophic (QG) oceanic motions as the main factor of long-term oceanic variability. In particular, horizontal diffusion of scalars, such as heat and biogeochemical quantities, is modeled based on parameterizations of 2D eddy turbulence effects dominated by baroclinic QG motions, and the mean advection is attributed to ocean currents. However, the shallow-water equations also contain high-frequency solutions known as inertia-gravity (IG) waves. The role of the baroclinic (BIG) component of these motions, including internal tides, is the subject of this talk. Our theoretical and experimental studies indicate that these, essentially nonlinear, motions - which we treat as "wave turbulence" - may play an important role in the horizontal transport of tracers, in the spatial variations of tracer concentration, and in the overall energy and momentum balance in some ocean regions. High-latitude regions are affected by this mechanism to a greater extent, for the level of BIG wave turbulence there is comparable to that of QG turbulence. A review of our theoretical and experimental results is presented with an emphasis on accounting for latitudinal variations of BIG wave field properties.

OS51D-11 1120h

Nonlinear Energy Transfer Within the Oceanic Internal Wave Spectrum at Mid and High Latitudes

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In order to examine how the energy supplied by M_2 internal tides cascades through the local internal wave spectrum down to dissipation scales, two sets of numerical experiments are carried out where the quasi-stationary internal wave spectra at 49°(experiment I) and 28°(experiment II), respectively, are first reproduced and then perturbed instantaneously in the form of an energy spike at the lowest vertical wavenumber and M_2 tidal frequency. These experiments attempt to simulate the nonlinear energy transfer within the quasi-stationary internal wave fields over the Aleutian Ridge and the Hawaiian Ridge, respectively, both of which are generation regions of large amplitude M_2 internal tides in the North Pacific. In experiment I, the energy spike stays at the lowest wavenumber where it is embedded and the spectrum remains quasi-stationary after the energy spike is injected. In experiment II, in contrast, the energy level at high horizontal and vertical wavenumbers rapidly increases after the injection of the energy spike, exhibiting strong correlation with the enhancement of high vertical wavenumber near-inertial current shear. This implies that, as the high vertical wavenumber near-inertial current shear is intensified, high horizontal wavenumber internal waves are efficiently Doppler shifted such that the vertical wavenumber rapidly increases and hence enhanced turbulent dissipation takes place. The elevated spectral density at high vertical wavenumber near-inertial frequency band which plays the key role in cascading energy to dissipation scales is thought to be caused by parametric subharmonic instability. In experiment I, in contrast, M_2 tidal frequency is 1.2 times the inertial frequency at 49°so that M_2 internal tide is free from parametric subharmonic instability. Accordingly, even though large amount of M_2 internal tidal energy is available, it cannot be efficiently supplied for the local deep water mixing.

OS51D-12 1135h

Large Internal Waves in Massachusetts Bay: Modeling generation, propagation and dissipation.

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A comprehensive model to study the generation, propagation and shoaling of large-amplitude internal waves in Massachusetts Bay has been developed, to be used to interpret data collected during the 1998 Massachusetts Bay Internal Wave Experiment. The model solves the Euler equations in a two-dimensional channel with variable depth, mimicking the topography observed in Massachusetts Bay. Six different combinations of tidal forcing and stratification have been considered. Nonlinearity dominates the dynamics during the generation phase over Stellwagen Bank in all cases considered, when a depression forms over the bank during ebb (eastward) tidal flow. As the tidal current slacks and turns westward, the western side of the depression leaves the crest, undergoes an initial smoothing due to the effect of the dropping bottom, until it reaches Stellwagen Basin, where nonlinearity steepens the front until an undular bore develops. Forcing intensity and pycnocline depth are shown to control the release time and smoothing of the initial depression. The shoaling of the undular bore depends on the amplitude of the bore itself, as well as the depth of the pycnocline. If the amplitude of the first wave of the undular bore is such that the pycnocline is displaced deeper than the half-depth mark, a rarefaction wave is generated traveling onshore as the bottom shoals from the basin to the coast, while the flow near the bottom is strongly accelerated and the remaining waves making up the train become unstable and collapse. In this case, the flow becomes again hydraulically controlled. The collapse was observed in all cases except one, characterized by a shallow pycnocline and relatively small waves. In this case, the undular bore was able to reach the shoal area west of the basin with relatively minor transformations, coherent with the dynamics implied by KdV.

OS51E HC: 319 B Friday 0830h

Stratified Coastal and Estuarine Circulation VI

Presiding: **A Valle-Levinson,** Center for Coastal Physical Oceanography Department of Ocean, Earth and Atmospheric Sciences Old Dominion University**; C T Friedrichs,** Virginia Institute of Marine Science

OS51E-01 0830h

Observations of Hypersaline Conditions in Florida Bay by Airborne Remote Sensing.

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Observations of sea surface salinity from an airplane mounted Scanning Low Frequency Microwave Radiometer (SLFMR) have been obtained in a multidisciplinary study of coastal buoyancy jets. These measurements include overflights of the Florida Bay region in June, 2001. The airborne salinity measurements provide rapid surveys of salinity over the region of the Bay on a time scale of a few hours. Simultaneous insitu measurements of temperature and salinity were obtained from a coastal research vessel. Salinities in the Florida Bay waters have been observed above 45 psu. Hypersaline conditions in the Bay are due to very shallow depths, which limit circulation and exchange with offshore waters, so that the Bay acts as a hypersaline lagoon. Recent hypersaline conditions are also related to reduced freshwater flow from the Everglades region. SLFMR surveys are used to identify freshwater sources, their regions of influence on surface salinity in the Bay, and regions of limited circulation.

These observations of hypersaline conditions are at salinities above the range of the Klein-Swift model of seawater dielectric constant (used in the inversion of remotely sensed brightness temperature to salinity). At present the model is based on few data points at salinities above 35 psu. Efforts are being made to extend the Klein-Swift model to salinities over 45 psu (at high temperature) to calibrate these observations.

OS51E-02 0845h

Features of Coastal Buoyancy Jets Observed With an Airborne Surface Salinity Mapper

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Beginning in July, 2000, The Scanning Low Frequency Microwave Radiometer (SLFMR) was deployed in an NRL-sponsored multi-disciplinary study of coastal buoyancy jets (CoJet). The radiometer was flown several times over the continental shelves of the US east coast and Gulf of Mexico using a suitably outfitted twin-engine Piper Navajo Chieftain charter aircraft.

Using this system, extensive surveys of sea surface salinity distribution were obtained on a time scale of a few hours. The resulting data were corrected for known environmental influences and field calibrated using seatruth data from oceanographic research vessels. The