Theory and Modeling of Internal Wave Generation in Straits

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LONG-TERM GOALS

The long-term goal is to improve understanding of the generation of nonlinear internal waves by stratified flow over sills (e.g. straits) and shelves.

OBJECTIVES

The primary objective will be on connecting the generation process with the dynamics of the disintegration of the radiated internal tide into shorter, nonlinear internal solitary-like waves and to predict the space and time scales for the emergence of waves and their properties (e.g. wave amplitudes, numbers, etc.). A central aspect of this work is to explore the role of rotation in the process. Rotation permits the presence of periodic, nonlinear inertia-gravity waves (i.e., the tide) that can act as attractors and arrest the steepening of the internal tide, and hence affect the production of the shorter solitary-like waves (Gerkema, 1996; Helfrich and Grimshaw, 2008). A second objective is to study the conditions that promote production of modal nonlinear internal waves on continental shelves from internal tidal beams generated at locations of critical slopes on the continental slopes. Again, the role of rotation will be explored.

APPROACH

The approach combines theoretical wave evolution models and numerical solutions of these models and solutions of the full Navier-Stokes equations. The theoretical models require some simplifications including restriction to two-layer flows and one-dimensional propagation. The presence of rotation requires flow in the direction transverse to the propagation; however, variations of properties in this direction are ignored. The theory is an extension of the fully nonlinear, weakly non-hydrostatic internal wave theory of Miyata (1988) and Choi and Camassa (1999) to include rotation (Helfrich, 2007). This model is termed MCC-f. In order to study the generation process, variable topography has been included in the model. This reduced wave equation model is complemented using a 2.5-dimensional Navier-Stokes numerical model that permits continuous stratification, variable topography, and eliminates restrictions associated with the long-wave assumption in the theory. These modeling studies will be compared with the IWISE field study results as they be come available and will help in the planning of those observational efforts.

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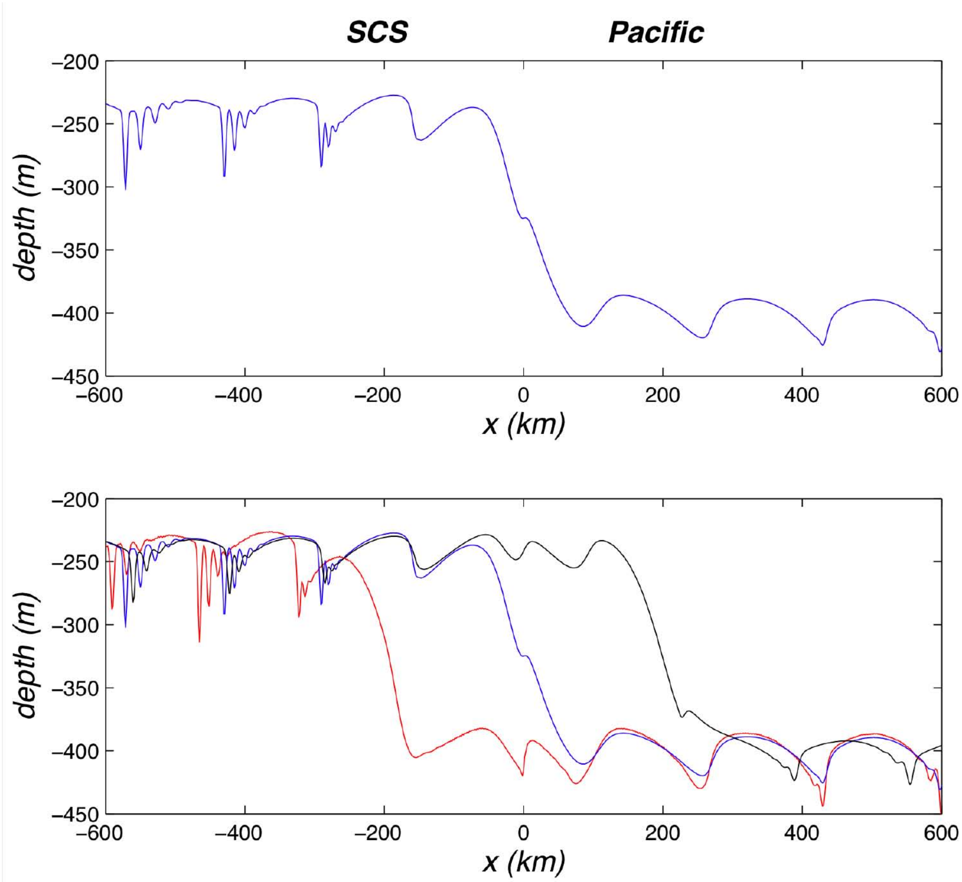

Figure 1. Calculations of the internal tide/nonlinear internal wave generation at the Luzon Strait in the presence of the Kuroshio Current. The calculations use the two-layer MCC-f model. The top panel shows the interface postion after six periods of the semi-diurnal tide in an example where the Kuroshio is centered over the sill. The sill crest is located at x = 0 and is 500 m deep (not visible in the plots). The deeper thermocline in the Pacific leads to a reduction of the relative effects of nonlinearity, allowing rotation dispersion to balance the nonlinearity and inhibit the production of nonlinear solitary-like waves when compared to the evolution in the SCS where the internal tide steepens to produce large amplitude solitary-like waves. The lower panel shows two additional cases where the mean position of the Kuroshio is 200km to the west (red) and east (black) of the sill crest.

WORK COMPLETED

The two-layer model MCC-f model has been applied to the generation of the internal tide and nonlinear internal waves for conditions that approximate the Luzon Strait topography, tides and stratification.

RESULTS

Preliminary numerical experiments on internal tide generation from a sill that approximates the Luzon Strait topography. The model used for these calculations is the two-layer MCC-f model which imposes no variations in the flow in the direction (*y*) transverse to the wave propagation. Because the flow is rotating the model does permit flow in the *y*-direction. The focus has been on the role of rotation on the production of internal solitary-like waves. Satellite observations and other in situ measurements indiate that the large amplitude solitary waves commonly found west of the Luzon Strait in the South China Sea (SCS) are largely absent in the Pacific Ocean to the east of the strait. One possible explanation for this asymmetry is the combined roles of rotation and the presence of the Kuroshio Current in the vicinity of the strait. In the model the Kuroshio is approximated as a geostrophic current with width of about 150 km and 160 m interface displacment with the mean interface deeper on the Pacific side. In the example calculations shown in Figure 1 the forcing is by the semi-diurnal barotropic tide with maximum currents in the *x*-direction (normal to the sill) of 30 cm/s. The top panel of Figure 1 shows the interface after 6 periods of tidal forcing when the model response has become periodic. In this example the Kuroshio is centered on the sill crest. In the SCS the internal tide steepen and nonlinear internal wave packets emerge. On the Pacific side, where the mean interface is deeper, the disintegration of the internal tide into nonlinear interal waves is much delayed and deminished. This is a consequence of the relative dominance of the rotational dispersion over non-hydrostatic dispersion in arresting the nonlinear steepening of the internal tide (Gerkema, 1996; Helfrich and Grimshaw, 2008). Essentially, the deeper thermocline in the Pacific decreases the nonlinearity of the radiated internal tide, allowing rotational dispersion to balance nonlinearity and inhibit the production of nonlinear internal waves. In the SCS the rotational dispersion is weaker (or nonlinearity stronger) and nonlinear waves are produced.

The lower panel of Figure 1 compares two runs that are identical to the top panel except for the position of the Kuroshio, which has been shifted 200 km west and east of the sill. Shifting the Kuroshio to the west (and dropping the interface over the sill) produces larger internal tides on both sides of the sill compared to shifting it to the east. However, the main conclusion that the presence of the Kuroshio, and hence deeper thermocline in the Pacific, reduces the production of nonlinear internal waves in the Pacific remains.

These calculations are highly idealized and only meant to explore basic ideas about the role rotation plays in the generation and disintegration of the internal tide. Future work will continue these idealized calculation and incorporate more realistic continuous stratification and topography by employing a 2.5 dimensional nonhydrostatic numerical model.

IMPACT/APPLICATIONS

The ubiquitous nature of large amplitude internal solitary waves in the world’s coastal oceans and marginal seas is clear from observations. These waves are can have significant effects on coastal mixing through breaking as they propagate and shoal, and they may also lead to substantial horizontal mass transport. Since the waves are frequently generated through the radiation of an internal tide by barotropic tidal flow over localized topography (as is apparently the case at in the Luzon Strait), this work will help understand what fraction of the energy put in at the tidal frequency ends up as internal solitary waves, the space and time scales for that transformation, and the characteristics of the resulting solitary-like waves.

RELATED PROJECTS

This work is an outgrowth of earlier studies under the NLIWI DRI.

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PUBLICATIONS

None yet.