Benthic Resuspension by Internal Wave Stimulated Global Instability

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LONG-TERM GOAL

The goal of this work is to contribute toward an understanding of how long internal waves on the shelf region affect the optical properties of the water column and issues related to remote sensing of the coastal ocean.

OBJECTIVE

Our work is directed toward providing a mechanistic understanding of and a predictive basis for processes whereby long internal waves interact with and stimulate resuspension from the bottom boundary. We also seek to provide insight regarding the effect of long internal waves on the transport of sedimentary and biological particles in the water column, both vertically and horizontally, and how the distribution of these particles might impact remote sensing of motions and processes on the shelf region.

APPROACH

Our approach is to develop an understanding of resuspension and particulate transport processes by means of theoretical modeling and numerical simulation. We also interact with field and laboratory investigators and collaborate on data analysis, model validation, and interpretation of results.

WORK COMPLETED

Analysis of topographic resonance for internal waves in sheared currents, together with the associated boundary layer structure, has been analyzed for various realistic thermoclines. The models of structured thermoclines provide a useful basis for a climatology study of long internal wave packets. Theoretical modeling and numerical simulations of the boundary layer dynamics under a particular class of long internal waves in shallow seas has been completed, as well as analysis of a number of striking resuspension events captured in the CMO data set. In addition, analyses and simulations have been completed which reveal the capacity for long internal waves to contribute to the formation of thin layers of near-buoyant particles. Very recently, horizontal transport by shoaling internal waves undergoing both polarity reversing and inter-modal energy conversion has been initiated. Also, models for describing the evolution of long internal waves in confined and semi-confined basins have been developed to define important dynamical characteristics of the internal wave “climate” in basins where significant excitation by surface wind stresses occurs.

RESULTS

The coupling between long internal waves and the bottom boundary layer has been examined in considerable detail for one class of waves, namely, those associated with resonant topographic generation and propagation against an oncoming shear flow. This case was selected for initial study because it mimics the class of internal-wave/boundary-layer interaction where definitive evidence of elevated rates of resuspension stimulated by long internal waves was reported (Bogucki et al, JPO, 27:1181-1196, 1997). The boundary layer under the footprint of a solitary wave of elevation is found to exhibit a sudden onset of a peculiar dynamics (a global instability) as the wave amplitude exceeds a threshold value. The global instability in the boundary layer creates regions of coherent vortex structures and locally steep gradients in the bottom stress. We find that critical wave amplitudes required to stimulate global instability in the boundary layer, which is a fully nonlinear dynamics, decrease quite rapidly as the boundary layer Reynolds number increases, and that the coherence of the unsteady dynamics persists to quite high super-critical conditions (Wang& Redekopp, 2001). Characterization of the boundary layer dynamics at higher Reynolds numbers and consideration of other types of wave packets has been carried forward (Wang, Ph.D. dissertation, 2002).

We have examined extensive records in the CMO data set and have identified several important features coincident with episodic bursts of resuspension. A number of remarkably strong resuspension events have been identified and analyzed. These events are correlated with long internal wave packets, generally propagating against the tidal current. We have also noted the concurrent presence of both mode-1 and mode-2 internal waves in a number of episodes with significant resuspension. In addition, we have noted the presence of mode-2 and pronounced peaks in resuspension under conditions when the polarity of longwaves switches from that of depression to elevation (due to the deepening of the mixed layer by strong, persistent surface wind events). The latter observation is also consistent with the resuspension – global instability mechanism developed and applied in our studies

Recently we have participated in a joint field experiment aimed at elucidating the role of shoaling, long internal waves near Huntington Beach, CA on resuspension and transport in near-shore regions where episodic elevations of bacterial levels have forced closure of the recreational areas (with serious attendant financial impact). This work was carried forward in cooperation with the USGS and the OCSD (Orange County Sanitation District). As part of our observational effort we captured images of a ‘red tide’ event (see the image shown below). The image shown in Figure 1 below reveals structure at about the 10 m depth, marginally below the base of the mixed layer (observed using particular digital filters and taken by Dr. Darek Bogucki). There is a clear cut-off position of the ‘red tide’ as one moves toward deeper waters, together with coherent variations in lateral intensity. Preliminary calculations suggest that the cut-off position closely coincides with the region where mode-1 internal waves undergo a polarity reversal, with attendant reversal of horizontal transport in respective layers. The lateral variations in the intensity of the red color are believed to be associated with secondary circulations generated by packets of long internal waves passing over undulating topography. These issues are currently under study both via simulations of model systems and data analysis.

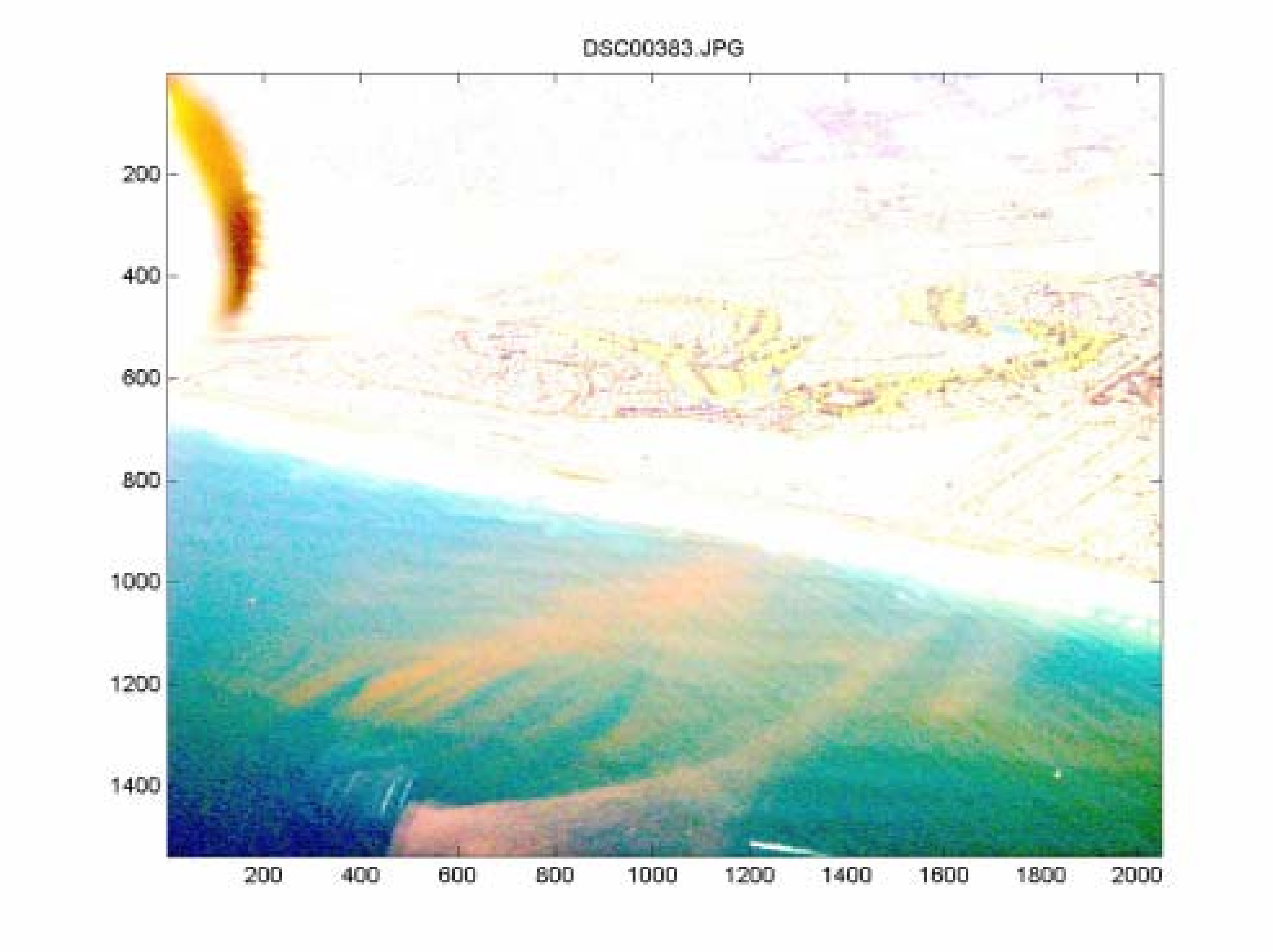

Figure 1. Image taken during a fly-over of Huntington Beach, CA with a digital camera sampling at a depth near the base of the mixed layer, and showing a peculiar spatial distribution of a "red tide."

In further work, we have examined the consequence of propagating packets of long internal waves on the concentration of particulates distributed in the water column. Our results show that the passage of a wave packet can create distinct layers with dramatically reduced vertical scale containing locally enhanced concentrations of near-buoyant particles, especially those whose particle Reynolds number is of order one or larger so that their motion is described by a nonlinear drag law (cf., Wang et al., JGR, 2001, to appear). We believe that these results may have particular relevance to issues of remote sensing and the coupling of internal waves and biology.

RELATED PROJECTS

In a related project we are seeking to apply our ideas about resuspension and transport processes to issues relevant to the ecology and biology in closed basins like lakes and reservoirs where the important dynamics involves long internal waves excited by surface wind stresses. We have developed and tested an evolutionary model for long internal waves in a two-layer system described by a rationally-derived KdV model with wind forcing and benthic dissipation. The model is being tested in collaboration with researchers at the Centre for Water Research at the University of Western Australia.

We have recently extended this model to incorporate multi-modal evolution in variable depth and width basins under wind forcing.

In addition, as described above, we have been interacting with the Orange County Sanitation District, and participating in a field experiment, in relation to the role of internal waves and tides on bacterial transport in the vicinity of Huntington Beach, south of Los Angeles. Preliminary results point to a prominent role of long internal waves in driving on-shore and along-shore transport.

IMPACT

The mechanism whereby long internal waves can give rise to elevated rates of resuspension is believed to have applicability to other wave-related events as well where temporally-varying fields interact with surface boundary layers. In this sense, the current effort might lead to a better understanding of the resuspension process in other flow contexts. Certainly the consequences of the spatio-temporal hydrodynamic processes being studied in this effort for particulate transport and the creation of layers of elevated concentration of particulates is believed to be of particular significance for optics and remote sensing.

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