Topographic Effects on Stratified Flows

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LONG-TERM GOALS

To use measurements and develop theory for stratified flow past topography. To understand the relevant processes, including establishment of the high drag state, the role of boundary layer separation, entrainment, and the generation, propagation and dissipation of internal solitary waves.

OBJECTIVES

To analyze the behavior of stratified flows in the neighborhood of a variety of topographic features, in channels, inlets, straits and in the open ocean, using both measurements and theory, so as to understand the relevant dynamics.

APPROACH

We have carried out observations of both tidally forced and density forced controlled flows using ship based instrumentation and aircraft. The observations have been acquired over the Oregon shelf, where we studied flow over a bank and the generation and propagation of internal solitary waves, and in Knight Inlet where we have tracked the behavior of strongly forced flow and its formation of large amplitude internal solitary waves and undular bores. Modeling efforts have primarily made use of two layer representations, but also include effects of entrainment.

WORK COMPLETED

This year we completed our analysis of strongly forced flow over a sill (Armi and Farmer, 2002) and addressed an issue of the interpretation of observations in the light of some prior numerical modeling efforts that fail to properly account for effects due to boundary layer separation (Farmer and Armi, 2001). Observations of internal solitary waves over the Oregon continental shelf were analyzed so as to determine their evolution under the influence of changing stratification, current and water depth. A paper on vortex pairing in an unstable anticyclonic shear flow was seen through to publication.

RESULTS

Stratified flow over topography presents challenging fluid dynamical problems with far reaching implications for circulation and mixing in the ocean and atmosphere. A distinguishing feature of controlled flows over topography is the formation of a wedge of partially mixed fluid downstream of a bifurcation or plunge point. This wedge of fluid is illustrated in fig.1, an acoustic image with

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14. ABSTRACT
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15. SUBJECT TERMS

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superposed velocities taken at the time of the photograph . This wedge of partially mixed fluid is displaced downstream as the flow undergoes a continuous transition from control over the obstacle crest to an uncontrolled state. The effects of changing barotropic forcing and relative density difference between the plunging flow and partially mixed layer above, combine to determine the fluid dynamical response described by Armi and Farmer (2002).

Note that upstream of this plunging flow a train of internal waves has formed. The essential aspect of the wave generation mechanism identified here involves upstream influence arising in the hydraulically controlled flow over the topography.

Notwithstanding the interest they have aroused in various contexts, the generation of internal solitary waves remains poorly understood. There are several mechanisms that have been proposed. Holloway et al. (1997) described the transformation of internal tides eover the NW Australian shelf, in which steepening and dispersion of the interface lead to solitary wave packets with well defined signatures. This transformation is accomplished over a considerable distance and, while clearly accounting for the waves seen there, cannot explain wave generation in many other environments. Specifically, tidal flow over a sill appears to generate solitary wave trains very close to the area of topographic interaction. These include, for example, the formation of waves following relaxation of a hydraulic response, waves generated through finite amplitude intrusions, and the escape of lee waves trapped over a sill.

But our observations in Knight Inlet show that the generation mechanism is related to establishment of the strongly forced flow and its hydraulics. Our observations of internal solitary waves over the Oregon Shelf, show how these waves decelerate as they move inshore, under the influence of dissipation and environmental factors. This is also ongoing work with a second research cruise and aircraft flights completed in Oct. 2001. **C**omprehensive observations have generally been lacking and we are fortunate to have two extensive data sets available, Knight Inlet and the Oregon Shelf for analysis.

Our studies of the transition of strongly forced controlled flows over a sill show the way in which control may be lost over the sill crest, a result successfully compared with two-layer models. A controversy over the mechanism by which stratified flow over topography makes the transition to the high drag state, has been shown to result from a failure of numerical models to properly account for boundary layer separation, thus clarifying the role of processes omitted from the models (Farmer & Armi, 2001).

IMPACT/APPLICATIONS

These results contribute to our ability to predict flows in stratified coastal environments, especially in the presence of topography and tidal or estuarine forcing, by demonstrating the underlying mechanisms. The stratified flow results apply as well to severe downslope winds which occur in the atmosphere and are a hazard to aircraft.

In this regard, I have also been invited to write an article on stratified flow hyraulics for the Annual Review of Fluid Mechanics.

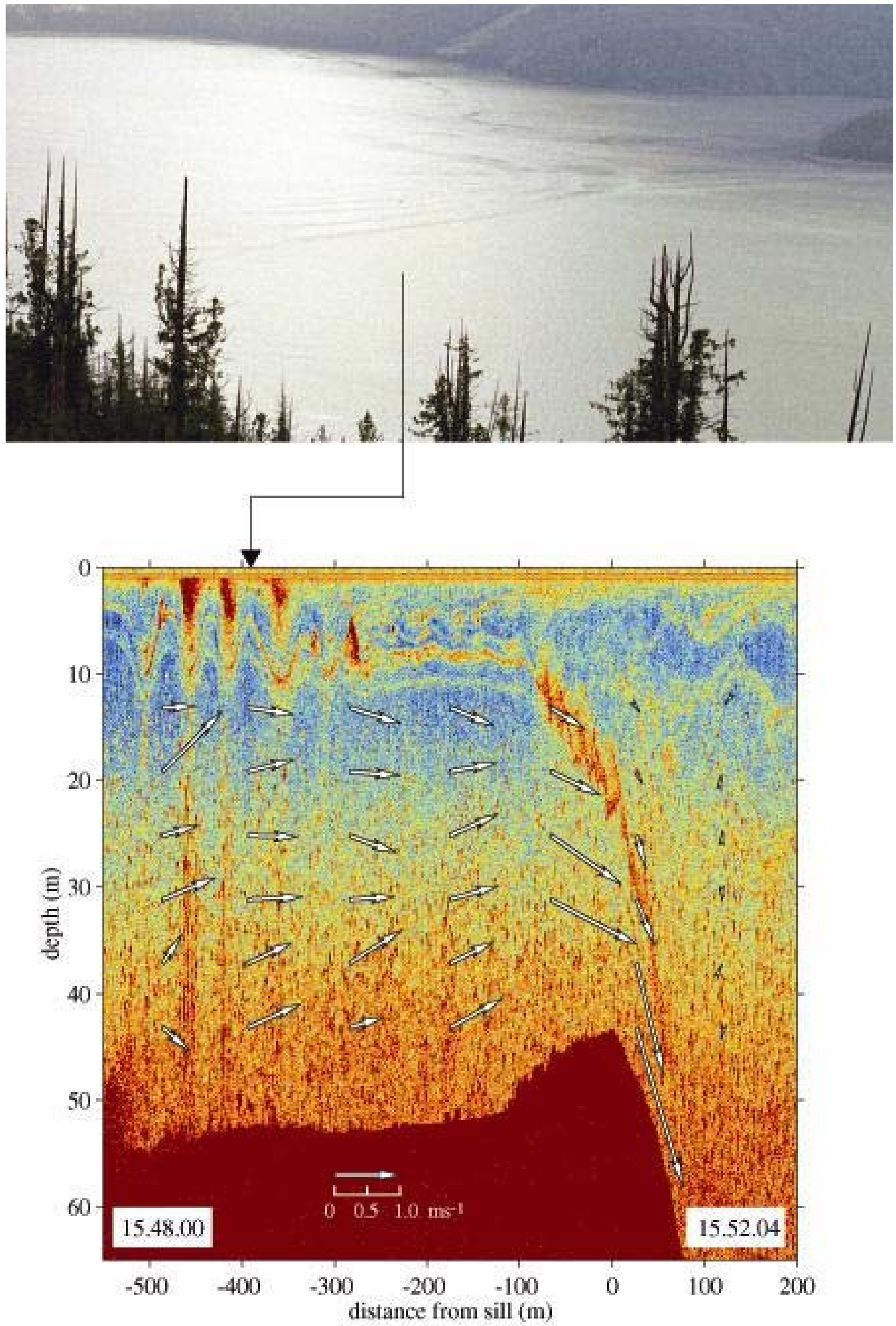

Figure 1. Echo sounder image showing upstream internal waves as an undular bore and the associated plunging downslope flow over the sill in Knight Inlet. Flow vectors are derived from ADCP. The corresponding photograph taken from a mountain ridge at 15.49.00 (UTC) shows the surface signature of the wave field as the boat was passing between troughs 3 and 4. The arrow relates the position of the boat on the photograph to the echo sounder image.

RELATED PROJECTS

Jim Moum's ONR funded studies of topographic flows over the Oregon Shelf.

David Farmer's ONR funded studies of stratified topographic flow and the generation of internal solitary waves.

Collaboration with Patrick Cummins on numerical modeling of upstream internal wave generation.

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