Stratified Flow Over Topography and Internal Solitary Waves

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LONG-TERM GOALS

Our long term goal is to use measurements of time varying stratified flow past topography to develop robust models of the relevant processes, including establishment of the high drag state, the role of boundary layer separation, friction and entrainment, and the generation, propagation and dissipation of internal solitary waves.

OBJECTIVES

Our objectives are to analyze the behavior of controlled flows in the neighborhood of a variety of topographic features, in channels, straits and in the open ocean, using both measurements and models, so as to understand the relevant dynamics.

APPROACH

Our approach includes observations of both tidally forced and density driven controlled flows using ship based and moored instrumentation. Our measurements exploit continuous density profiling, Dopple profiling, acoustic imaging and airborne photography. Our modeling efforts are focused on identifying key processes rather than achieving detailed simulations, and typically use layered representations, but may include effects of friction and entrainment.

Key individuals participating in the work:

- D M Farmer is an physical oceanographer, is the principal investigator responsible for project design and analysis
- S Vagle is an acoustical oceanographer responsible for implementation of acoustical systems and analysis
- C Garrett at the University of Victoria is a collaborator who has contributed to development of theoretical models.

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14. ABSTRACT
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15. SUBJECT TERMS

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- L Armi is a physical oceanographer from Scripps Institution of Oceanography who has participated in field experiments and analysis.
- J Moum is a physical oceanographer at Oregon State University with whom we are collaborating in our study of internal solitary waves over the Oregon Shelf.
- B Baschek is a graduate student at the University of Victoria who is studying strongly forced flows and their consequences, especially for air entrainment, with both observations and modeling.
- F Gerdes is a graduate student at the University of Victoria studying density driven exchange flows using both observations and modeling

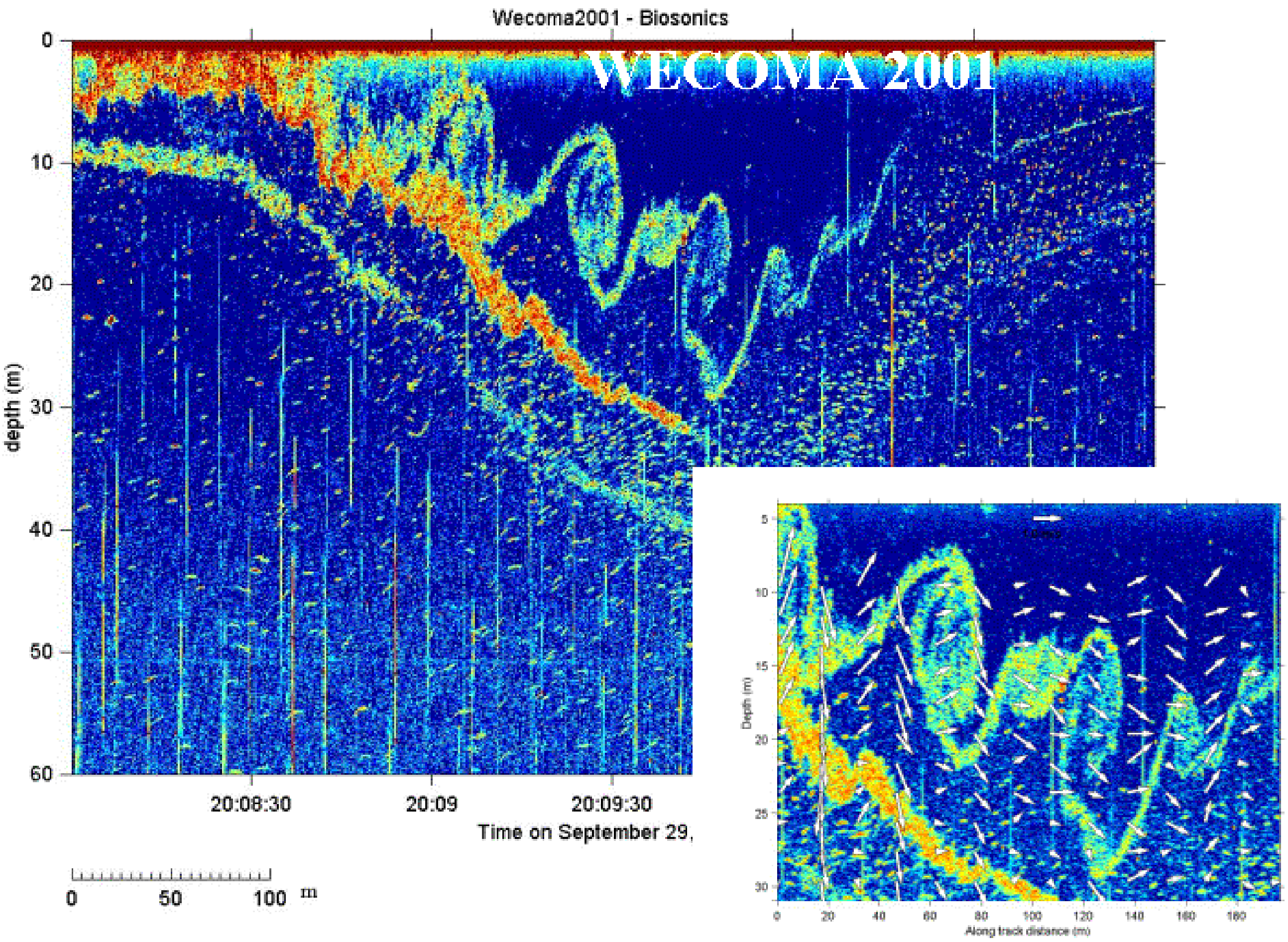

Figure 1 Acoustic image of internal solitary wave o over the Oregon continental shelf showing presence of unstable layer leading to vortex pairing. Inset: Segment of instability showing vertical-horizontal Doppler flow vectors within the instabilities.

WORK COMPLETED

Our collaborative analysis of observations of internal solitary waves with J Moum and L Armi led to an analysis of the role of these waves (see Figure 1) in the generation of turbulence and consequent mixing (Moum, Farmer, Smyth, Armi & Vagle, 2002 submitted). In a separate effort we also conducted an observational and numerical study of internal solitary wave generation over topography (see Figures 2 and 3). Our observations emphasize the role of upstream influence and steepening in generating an undular bore. These results in turn have motivated a further study of the adjustment that takes place at the crest of topographic features.

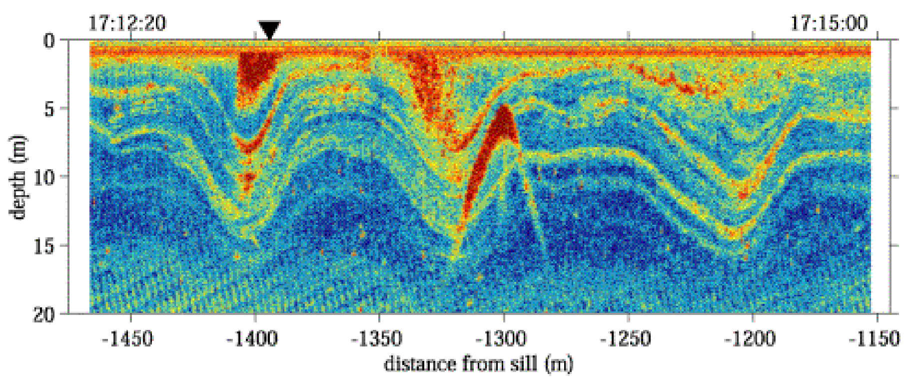

Figure 2. Air photo of internal solitary waves in the early stages after release, showing variability along the wave front. Lower image is acquired at the same time.

Our analysis of the role of small scale instability in the development of the established state for stratified flow over topography led to some controversy. Numerical models that fail to include all of the relevant physics can lead to alternative interpretations, especially with respect to the importance of large scale overturning internal waves. The discrepancy between models and observations is discussed by Farmer & Armi (2002). We completed and published our analysis of stratified flow past a headland (Farmer, Pawlowicz and Zhang, 2002). Finally, a model analysis was carried out of entrainment and friction effects on control in a layered exchange flow. This model is being used in studies of exchange flows in Straits (Garrett, Gerdes and Farmer, 2002).

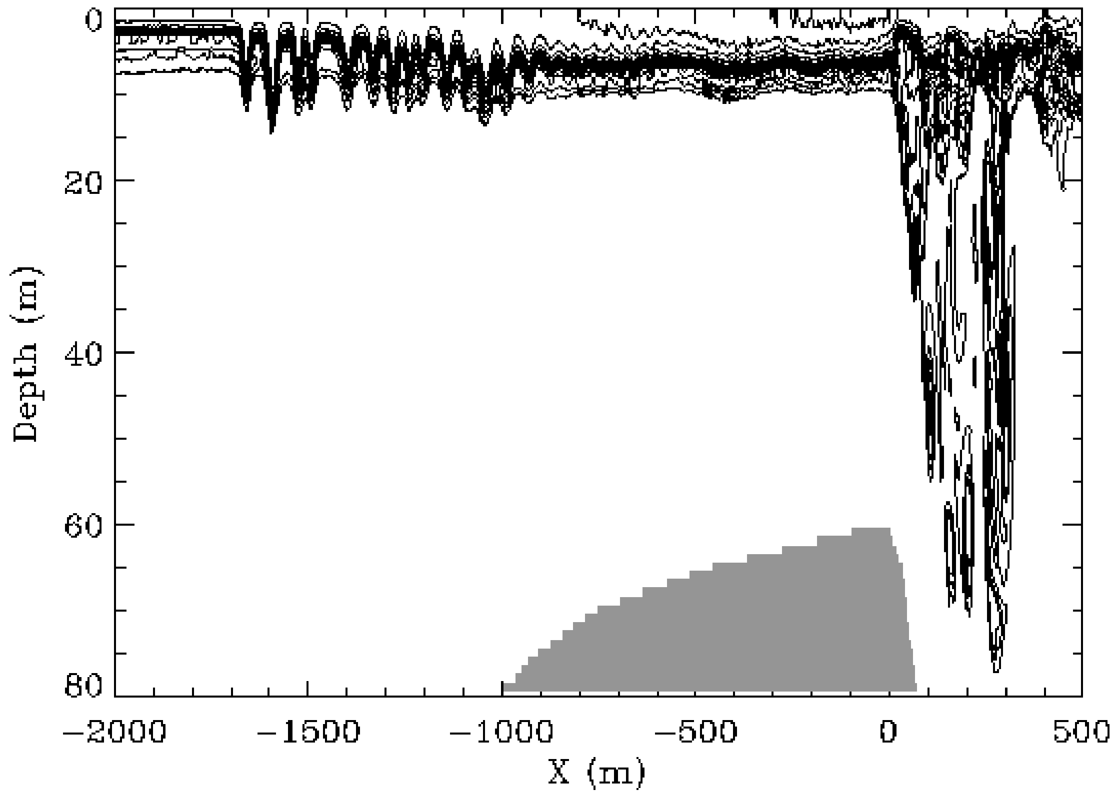

Figure 3. Contoured field of isopycnals from a nonhydrostatic numerical simulation of the Knight Inlet sill flow. A packet of internal solitary waves forms upstream of the sill crest on strong ebb tides. The packet is at first stationary, but eventually propagates in the upstream direction against the waning tidal flow. The image shows the isopycnals as the waves are released into the far field. Also evident are the plunging isopycnals found on the lee side of the sill, associated with the downslope flow.

RESULTS

1. Our observations of internal solitary waves over the Oregon Shelf, show their role in forming instabilities that lead to turbulence and mixing.

2. Our studies of stratified flow over topography shows the importance of including boundary layer separation in model calculations.

3. It has been shown that entrainment in two layer flows tends to push the flow towards the controlled state, a mechanism of importance in exchange flows

4. It has been shown that internal solitary wave trains are formed upstream of controlled flow over topography when the tidal forcing is sufficiently strong to generate a steepening of the upstream

influence. This result has been clearly shown in observations and demonstrated with numerical model calculations.

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 that have to be incorporated in robust fluid dynamical models.

RELATED PROJECTS

J Moum's ONR funded studies of topographic flows over the Oregon Shelf; M Gregg's studies of flow in the Bosphorus; L Armi's studies of instability and related phenomena in stratified flows.

REFERENCES

PUBLICATIONS

Armi, L., & D. M. Farmer, 2002, Stratified Flow over Topography: Bifurcation Fronts and Transition to the Uncontrolled States, *Proc. Royal Society*, A **458**, 513-538

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Farmer, D.M., Pawlowicz, R., & R. Zhang, 2001, Tilting Separation Flows: a mechanism for intense vertical mixing in the coastal ocean, in press *DAO*, 2002