

SOLITARY WAVES AND SILL FLOWS

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LONG-TERM GOALS

Our goal is to elucidate the fluid dynamical processes associated with stratified flow over topography including the establishment of such flows, effects due to strong forcing and the generation of internal solitary waves.

OBJECTIVES

The key scientific objectives are (i) to determine the mechanisms responsible for streamline splitting and the role played by entrainment in forming a weakly stratified wedge of nearly stationary fluid over an obstacle as the flow adjusts to changing barotropic forcing, (ii) to examine the detailed structure of instabilities in steeply inclined shear flows in the light of recent laboratory studies, (iii) to describe the mechanism responsible for generation, trapping and release of internal solitary waves above an obstacle.

APPROACH

Observations were acquired in a collaborative study in Knight Inlet, BC using a combination of ADCP measurements, echo-sounder imaging, continuous CTD profiling, use of towed current meters and CTDs at fixed depth and air photography.

WORK COMPLETED

Data from an extensive series of sill traverses have been mapped on to common coordinates using GPS positioning. Results of the time evolving flow establishment have been interpreted in terms of a combination of internal hydraulic theory and observations of small scale structure. This work is carried out in conjunction with D. Farmer (IOS).

RESULTS

We have found that the formation of a wedge of slowly moving and weakly stratified flow downstream of an obstacle is a consequence of entrainment. This result is in contrast to previous numerical simulations, used for example in the prediction of atmospheric flow over mountains, in which the mixing is attributed to the overturning of large scale lee waves. Figure 1 shows a single traverse in which the isopycnals are seen to intersect the

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entrainment zone to form weak stratification within the wedge of slowly moving fluid. Analysis of this process in the early stages of the flow shows that streamline splitting begins over the crest of the obstacle as a consequence of local shear flow instability. The instability leads to mixing that subsequently expands to form the nearly stationary wedge. The flow is observed to separate at the crest of the obstacle until the expanding wedge leads to a favourable pressure gradient suppressing the separation. The entrainment can be derived from the distribution of isopycnals and velocity field and appears consistent with Ellison & Turner's (1959) laboratory studies of inclined plumes, although lying at the low end of their distribution. The steep slope of the interface, which can reach $\sim 45^\circ$, provides a geophysical example of a class of instability that has recently been analysed by Pawlak and Armi in the laboratory.

During stronger forcing, the bifurcation point at the leading edge of the wedge can be pushed downstream past the obstacle crest. The flow upstream of the bifurcation remains subcritical and exhibits the interfacial deepening consistent with acceleration of the lower layer. The bifurcation point can be subject to unstable motions associated with propagation of growing instabilities in the downstream direction. Since the flow upstream of the bifurcation is subcritical, internal waves can propagate along the interface. Although long interfacial waves will always be able to escape upstream in the subcritical flow, short waves travel more slowly and the wave speed may be insufficient to allow passage, since the wave speed decreases upstream as the surface layer becomes thinner. Thus short internal waves can become trapped. These waves may grow as a result of the background shear, increasing in amplitude and assuming the algebraic form expected of solitary waves in shallow stratification above a deep layer. The gently sloping interface thus traps short waves allowing them to grow in amplitude until finite amplitude effects allow their escape. A train of several solitary waves was observed to be trapped for up to 2 hours in this way, before being released by the slackening tide.

Solitary waves may also be formed in the supercritical flow downstream of the control. In this case they may remain trapped by the balance between amplitude dispersion and convection by the supercritical flow. A train of solitary waves was observed to be trapped in this way for up to two hours.

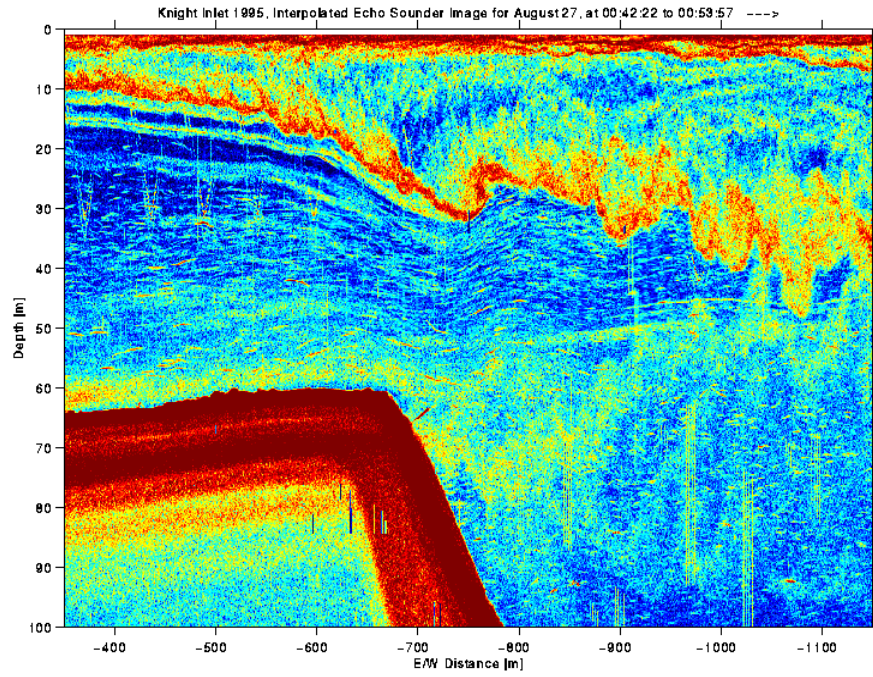


Figure 1a. Acoustical image of flow over a sill showing boundary layer separation from the crest and instabilities on the entraining interface between the rapidly moving deeper layer and the weakly stratified and slowly moving wedge of fluid above.

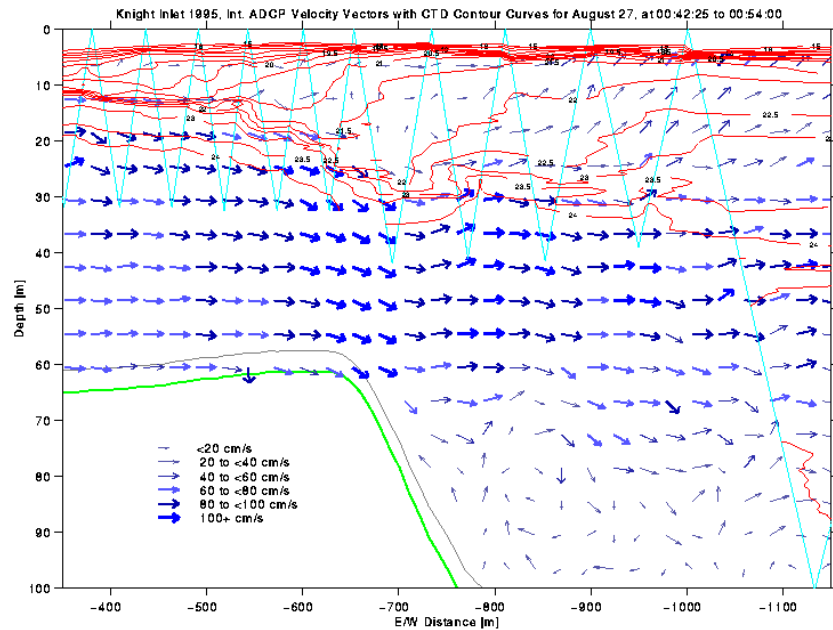


Figure 1b. Velocity vectors and isopycnals for stratified flow over a sill corresponding to the acoustical image in Figure 1a.

IMPACT/APPLICATIONS

These results provide a dynamical basis for calculation of drag over obstacles, especially in cases where the forcing is unsteady, for example due to tides. The results are directly relevant to atmospheric circulation models for which the effect of form drag due to mountains can account for 50% of the total. The measurements on entrainment provide confirmation of previous laboratory studies at geophysical scales and also illustrate a newly described class of shear instability in accelerating flows.

Although the surface manifestation of internal solitary waves is almost ubiquitous in coastal waters, the mechanisms associated with their formation are not so well understood. Typically they may be modelled as an evolution into a train of amplitude ordered waves from a single large scale interfacial disturbance, for example as described by the inverse scattering approach for KdV models. The present observations illustrate an entirely different mechanism that may be widespread. The waves in this case do not evolve from a single interfacial disturbance and are amplitude ordered by horizontal variability in the density structure and shear. This novel mechanism will need to be considered in the interpretation of solitary wave trains observed over topography.

TRANSITIONS

The results of this work form an essential component of the larger description of sill flows and solibores in the Knight Inlet study. Our new results of flow establishment are being discussed with atmospheric scientists with a view to studying their application to parameterisation of atmospheric flow over mountains.

RELATED PROJECTS

Concurrent work being carried out in my laboratory on the properties of shear flow instabilities on sloping interfaces is directly related to the field studies described here.

REFERENCES

Farmer D & L Armi, 1997: Establishment of stratified flows over topography by small scale entrainment and mixing, *submitted* Phil Trans Roy Soc A.