# Topographic Effects on Shelf Waters and Spirals on the Sea

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Grant Number: N00014-95-1-0024

## 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.

To elucidate the fluid dynamical processes associated with spiral eddies and other small scale vortices often observed in visible and SAR images from space and aerborne platforms.

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## 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.

To pursue possible ways to continue the study of spiral eddies using aerborne SAR combined with seagoing work.

## APPROACH

We have carried out observations of both tidally forced and density forced controlled flows using ship based and moored instrumentation. 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 the transition to the uncontrolled state. Our modeling efforts have primarily made use of two layer representations, but include effects of entrainment. In the study of mixing and entrainment in developing stratified currents, as well as in the study of spirals on the sea and other small scale eddies, we have taken the “coherent structures” approach to understanding these turbulent processes.

## WORK COMPLETED

This year we completed our analysis of strongly forced flow over a sill 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. Observations of internal solitary waves over the Oregon continental shelf were analyzed so as to determine their evolution under the influence of

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| # Report Documentation Page | *Form Approved*<br>*OMB No. 0704-0188* |

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|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2001** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2001 to 00-00-2001** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Topographic Effects on Shelf Waters and Spirals on the Sea** | 5a. CONTRACT NUMBER |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Institute of Geophysics and Planetary Physics,,Scripps Institution of Oceanography,,La Jolla,,CA, 92093** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S) |
| | 11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT

**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

**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. To elucidate the fluid dynamical processes associated with spiral eddies and other small scale vortices often observed in visible and SAR images from space and aerborne platforms.**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **6** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

changing stratification, current and water depth. A number of papers were completed and 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. As in our study of flow establishment we took advantage of the opportunities provided by flow over a sill in Knight Inlet, British Columbia. The bathymetry is shown in fig. 1 along with an aerial photograph. Our earlier study took advantage of weaker tidal forcing; the topic addressed in Armi and Farmer (2002) only occurs when the tidal current is strong enough to force the bifurcation and resultant surface expression or plunge line downstream to the sill crest or beyond.

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.2, an acoustic image with superposed velocities taken immediately after the photograph shown in fig. 1. 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.

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).

Our observations of internal solitary waves over the Oregon Shelf, show how they decelerate as they move inshore, under the influence of dissipation and environmental factors. This is ongoing work with a second research cruise and aircraft flights planned for Sept. through Oct. 2001.

In Munk, Armi, Fischer and Zachariasen (2000) we have published our analysis and partial explanation of spiral eddies. The spirals are broadly distributed over the world’s oceans, 10-25 km. In size and overwhelmingly cyclonic. Under light winds favorable to visualization, linear surface features with high surfactant density and low surface roughness are of common occurrence. The linear features are wound into spirals by vortices associated with horizontal shear instablility, modified by rotation. Two models for concentrating shear, a necessary preconditioning, are presented: a softened version of the classical Margules front and the time-dependent lagrangian model of Hoskins and Bretherton. Both models favor horizontal shear and resultant cyclonic spirals.

*Figure 1. Aerial photo from 300m altitude looking east along Knight Inlet, showing the CSS VECTOR approaching the sill. The surface expression of the plunge line associated with the flow shown in fig. 2 is marked on the photo. The inset below shows the bathymetry and shoreline oriented as in the photo with the viewing position, ship and direction of ebb flow.*

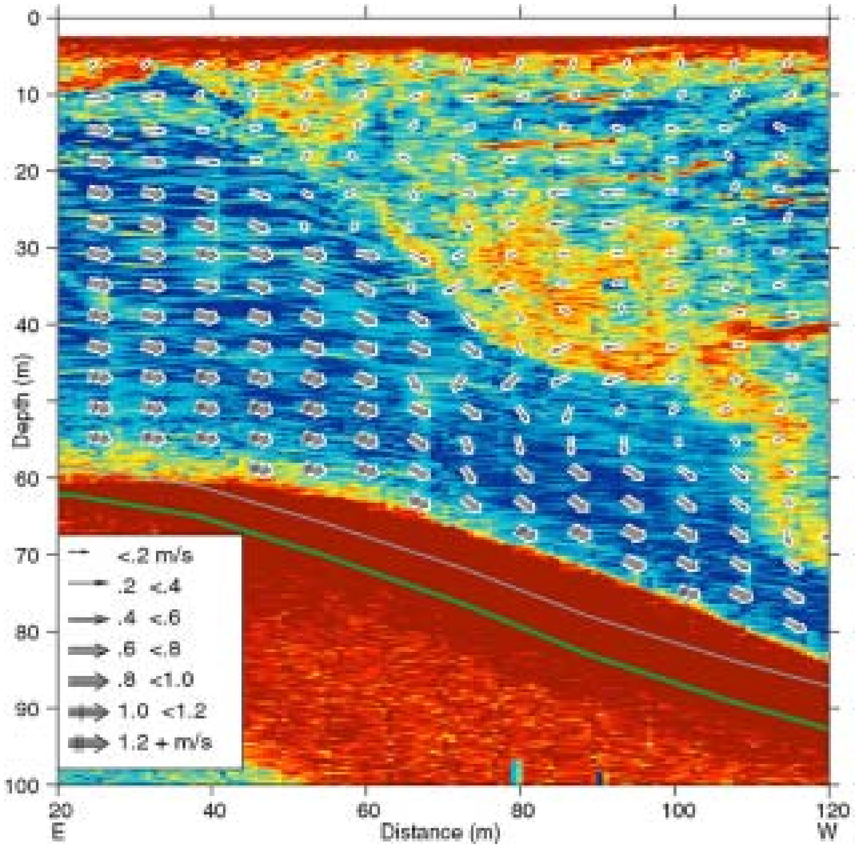

***Figure 2. Acoustic image at 1:1 aspect ratio looking to the south with superposed ADCP velocity arrows of the downslope flow over the sill. Note the beginning of the downslope flow starts at the sill crest, not upstream as in numerical simulations published to date.***

In Flament, Lumpkin, Tournadre and Armi (2001) we have completed the analysis of the downstream evolution of an oceanic horizontal shear flow formed as the westward North Equatorial Current passes the island of Hawai'i. Finite-amplitude anticyclonic vortices result from instability of the shear. The initial orbital period is exactly one pendulum day (3.1 days at this latitude), centrifugal instability presumably inhibiting stronger vortices from forming. As they move downstream they pair and merge into successively larger vortices, in a geometric sequence of longer orbital periods; three subharmonic transitions are suggested with final orbital periods near 6, 12 and 24 days. The data came from satellite-tracked drifting buoys and sea surface height anomaly above the mean geoid available from the ERS-1 and TOPEX/POSEIDON satellite altimeters.

## 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.

Estimates of horizontal mixing rates can now be made from the small scale eddies and spirals observed.

## 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.

Walter Munk's ONR funded studies on spiral eddies.

Pierre Flament's drifting buoy and satellite altimeter work.

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