Topographic Effects on Ocean Mixing

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Grant Number: N00014-9310479
http://maelstrom.seos.uvic.ca/

LONG-TERM GOALS

To understand and parameterize interior and near-boundary mixing processes in the ocean.

To understand the physical oceanography of straits and semi-enclosed seas.

OBJECTIVES

An ongoing objective is to exploit Juan de Fuca Strait as a natural laboratory for the study of rotating stratified shear flows with sloping lateral boundaries. In particular, I would like to understand and quantify vertical and lateral transfer of momentum and scalars, the causes and role of cross-strait secondary circulation, and the comparative importance, magnitude and parameterization of internal and near-boundary mixing.

Another overall objective is to investigate the role of topographic features, observationally in Juan de Fuca Strait and theoretically via calculations of internal tide generation in the deep sea.

For straits I seek to determine the role of friction, entrainment, and shear, and improve models relating strait exchange to the properties of semi-enclosed seas.

APPROACH

For the last several summers we have conducted observational studies in Juan de Fuca Strait involving one or more bottom-mounted 300 kHz broadband ADCPs, temperature and conductivity moorings, and CTD profiles and "towyos". Senior Research Associate Richard Dewey assumes much of the responsibility for this, with the involvement of graduate students Keir Colbo and Steven Stringer.

Studies of deep ocean mixing have involved theoretical calculations of internal tide generation and the consequences based on application and extension of existing theories and the development of new models. Much of this has involved postdoctoral fellow Lou St. Laurent and graduate student Steven Stringer.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Topographic Effects on Ocean Mixing**	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) **Department of Physics and Astronomy,Elliott Building,,University of Victoria,P.O. Box 3055,Victoria, BC,V8W 3P6, Canada, ,**	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
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

A new project, with postdoctoral fellow Mary-Louise Timmermans and Eddy Carmack of the Institute of Ocean Sciences, has involved an investigation of the vertical mixing processes in the Canada Basin in the Arctic Ocean.

Investigation of strait flows has mainly involved posing and resolving theoretical questions concerning the role of entrainment, frictional processes and shear. This is partly joint work with graduate student Frank Gerdes and David Farmer, now of the University of Rhode Island.

WORK COMPLETED

On a cruise in Juan de Fuca Strait in June 2002 we focused on a study of the effect on flow and mixing of an isolated bump with a scale of order a kilometer, rising 70 meters above the sea floor in water of depth 100 meters (Figure 1). On the southwestward ebb tide, in particular, undisturbed stratified water flows past and over the bump with a speed of about 2 meters per second. We moored two ADCPs in the lee and conducted extensive CTD and shipboard ADCPsurveys. The data will be used in a study of flow separation, mixing, trapping and upwelling caused by general topographic features.

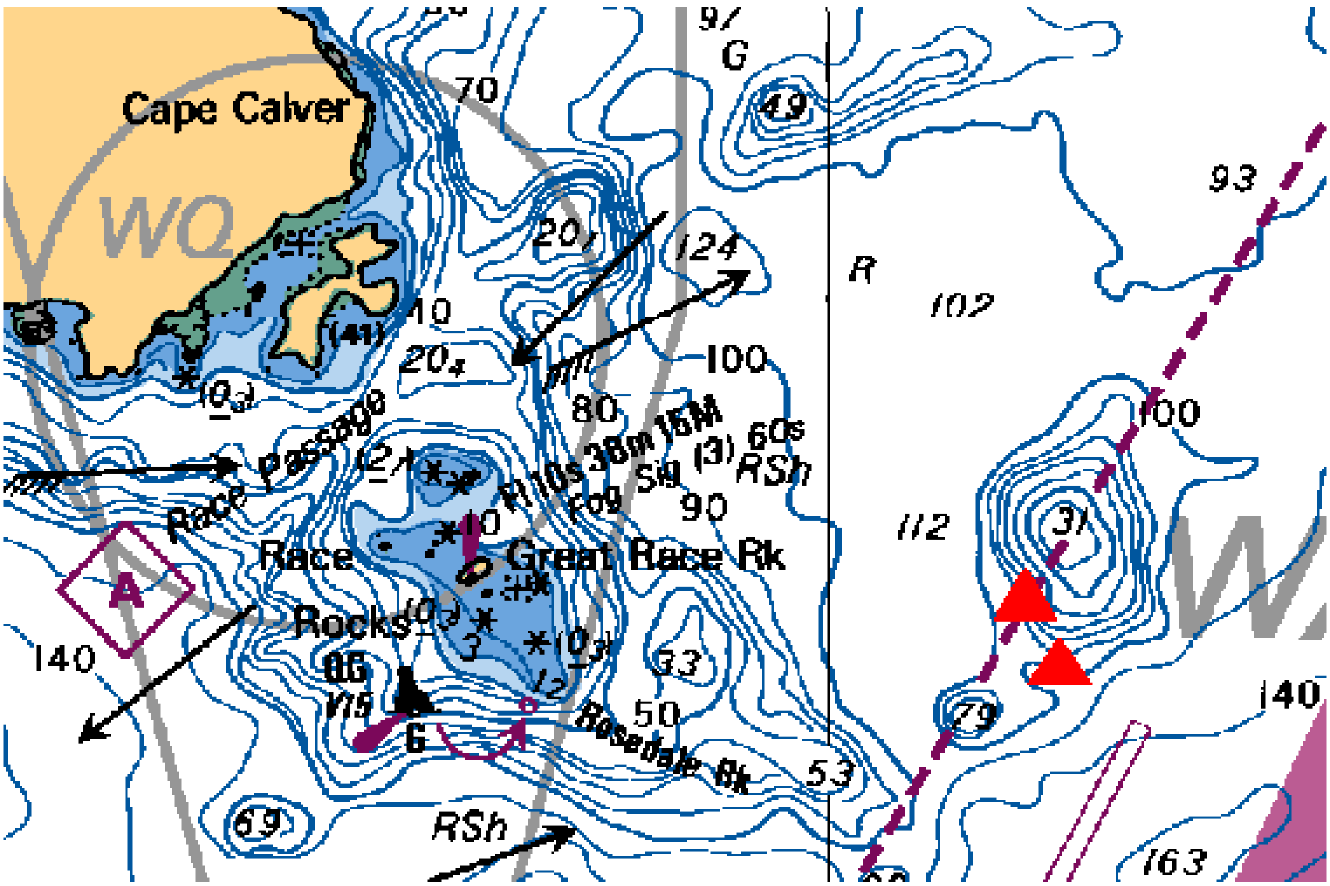

Figure 1. An isolated bump in the strong stratified tidal flows in Juan de Fuca Strait. The locations of moored ADCPs in the lee of the bump during ebb tide are shown as red triangles.

A study of internal tide generation at abrupt topography, for comparison with gentle, "sub-critical", features, has been completed.

A paradox concerning the appropriate hydraulic control conditions for a sheared homogeneous flow with friction has been resolved.

A new study of the thermohaline structure and evolution of the deep waters of the Canada Basin in the Arctic, using historical data, has been completed. A thermistor chain has been installed this year to gather further data over the next two years.

RESULTS

Earlier data collected with 300 kHz ADCPs and thermistor and conductivity chains near the sloping sides of Juan de Fuca Strait have led to the measurement of the lateral Reynolds stress and the detemination of a lateral eddy viscosity in this region of several m^2/s (Figure 2). The data also show the involvement of both internal waves and vortical modes. This study constitutes the PhD thesis of Keir Colbo.

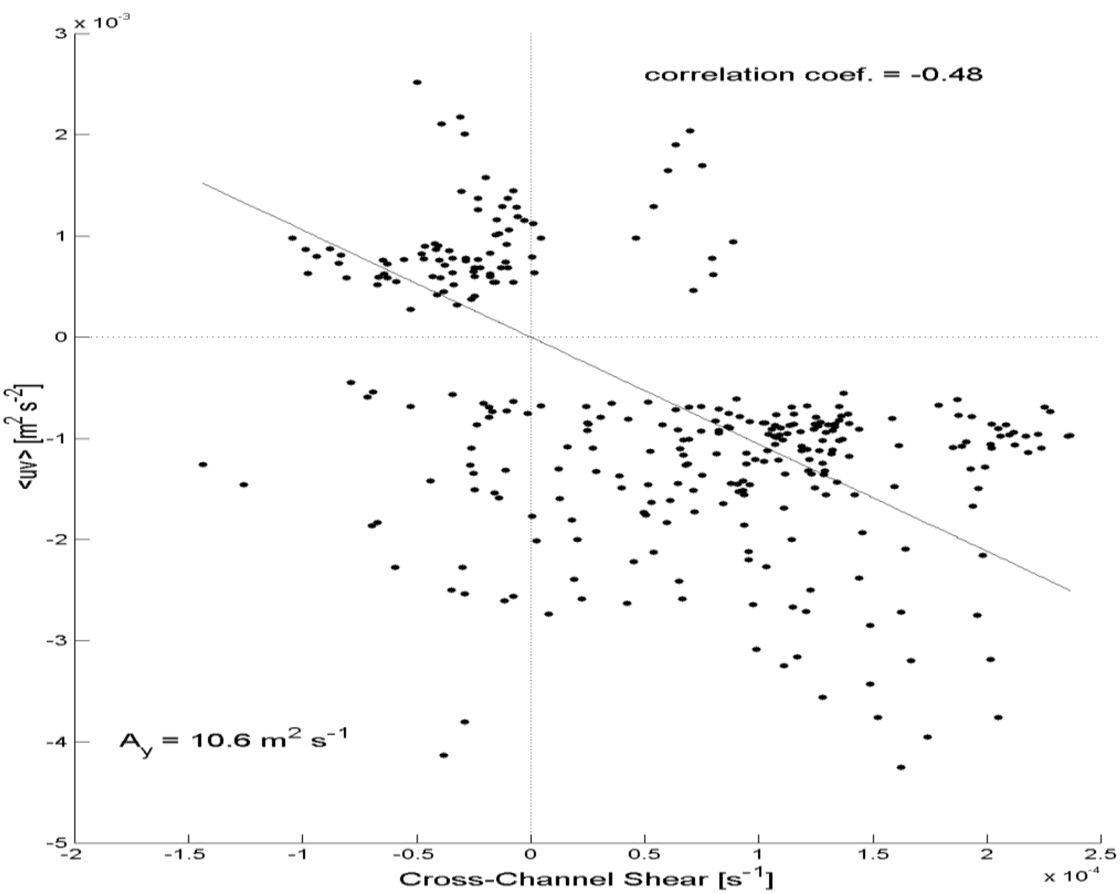

Figure 2. The lateral Reynolds stress near the sloping sides of Juan de Fuca Strait shows a correlation with the tidal shear that implies an eddy viscosity of approximately 10 m^2/s.

Internal tide generation at knife edges and abrupt steps has been compared with results for sub-critical topography. Figure 3 shows the ratio of the internal tide energy flux generated by a knife edge compared with that generated by a "Witch of Agnesi" profile of critical slope but using linear theory. One notable result is that for a very small ratio of the height of the feature to the ocean depth, the consequence of infinite slope is only to double the energy flux predicted by linear theory. For larger features, this amplification increases considerably.

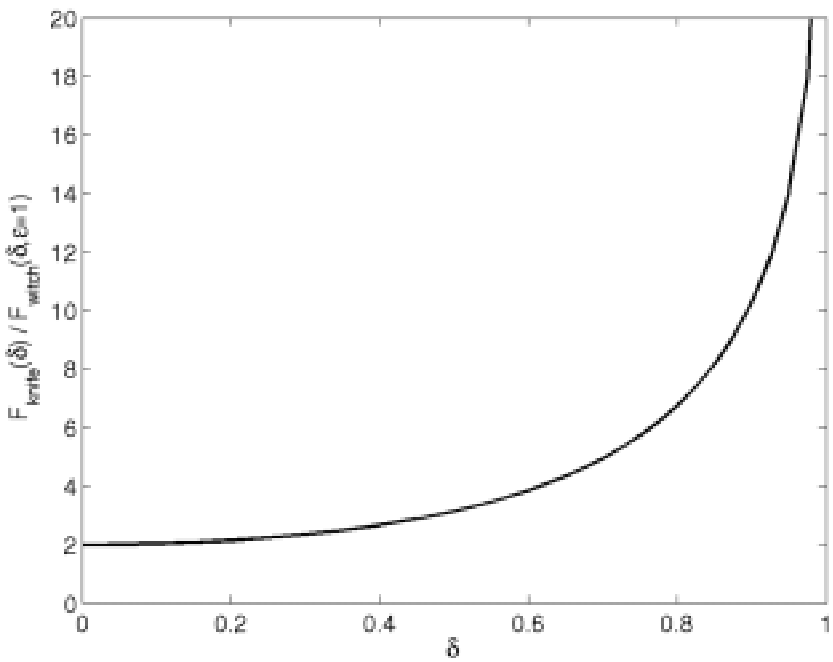

Figure 3 The ratio of internal tide energy flux from a knife-edge, compared to the linear theory prediction for a "Witch of Agnesi" profile of critical slope, as a function of the height of the feature compared with the ocean depth. The energy flux ratio increases from 2 for small height ratio to more than 10 when the height ration reaches 0.9.

For the deep Canada Basin, we argue that the geothermal heat flux is escaping via turbulent mixing in near-boundary regions rather than through a staircase structure in the basin interior. At first sight this appears to carry a significant double-diffusive heat flux, but the interfaces seem to be too thick and quiescent.

For frictionally-sheared flows of a homogeneous fluid, there has been confusion about the conditions for hydraulic control, with one approach suggesting that it occurs when the average flow speed is less than that of long waves. We find that this is indeed the case, but only for particular, and peculiar, assumptions about the form of internal friction. In general the long wave speed is a better guide.

IMPACT/APPLICATIONS

Our results on lateral Reynolds stresses should have implications for the modeling of estuarine flows, and shows the importance of making direct measurements rather than relying on circumstantial evidence for verification of model parameterizations.

The role of internal tides in mixing the ocean is receiving much attention. Our latest study helps to link calculations for subcritical and supercritical slopes. It also confirms that most of the energy flux typically goes into low modes which can propagate long distances.

Our analysis of the deep Canada Basin relied on extensions of Thorpe scale analysis. This is likely to become more prevalent in other situations as well as showing evidence for the importance of mixing near boundaries.

The new results on hydraulic flows with internal friction and shear should provide an intuitive basis for understanding real exchange flows.

Ongoing analysis of results from a Knight Inlet study will clarify the relative importance of turbulence and zooplankton in acoustic backscatter at various frequencies, and possibly provide clues to the effect of turbulence on zooplankton behavior. This is the PhD thesis of Tetjana Ross, largely supervised now by Rolf Lueck.

TRANSITIONS

We have frequent discussions with various colleagues at the University of Washington, particularly Eric Kunze and Parker MacCready, and with David Farmer of the University of Rhode Island.

RELATED PROJECTS

The projects described above are also supported by Canadian funding agencies with equal or greater contributions to salaries and equipment and full provision of shiptime.

PUBLICATIONS

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