Topographic Effects on Ocean Mixing

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LONG-TERM GOALS

To understand and parameterize interior and near-boundary mixing processes.

To understand the dynamical processes occurring in the surface layer of the ocean and parameterize them in ocean models.

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.

In the surface mixed layer I would like to understand and parameterize the effects of various processes responsible for mixing and for air-sea gas exchange.

For straits I seek to determine the relative importance of hydraulic and frictional processes, and to understand the nature and causes of variations on a variety of time scales.

An ongoing study also seeks to elucidate the comparative importance of turbulence and zooplankton for acoustic backscatter at various frequencies.

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 assistance from postdoctoral fellows (particularly Kate Stansfield) and graduate students Michael Ott, Keir Colbo, Tetjana Ross and Steven Stringer.

Studies of deep ocean mixing have involved theoretical calculations of internal tide generation and consequences based on application and extension of existing theories. Much of this has involved postdoctoral fellow Lou St. Laurent.

One recent theoretical investigation of strait flows, with graduate student Frank Gerdes and David Farmer, compared the effects of entrainment and friction.

A cruise to Knight Inlet, in June, 2001, in conjunction with Rolf Lueck's ocean turbulence group, collected in situ turbulence and acoustic backscatter data from a towed body, as well as multi-frequency shipboard acoustic backscatter data. This will form the basis of Tetjana Ross's Ph. D. thesis.

WORK COMPLETED

On a cruise in Juan de Fuca Strait in August 2001 we obtained extensive CTD profile data in the very vigorously mixing region near Race Rocks. The data will be used in a further study of the probability distribution of Thorpe displacements, for comparison with the results from earlier studies in mid-strait. We also conducted a preliminary survey of the stratified flow past an isolated bump rising from 100m to within 30m of the sea surface. This will be revisited in 2002 for a study of flow separation, mixing, trapping and upwelling caused by general topographic features.

A paper on the probability distribution of Thorpe displacements has been completed and accepted for publication. Another paper on internal stresses and secondary flows in the strait is under revision.

A theoretical assessment of the internal tide energy flux from general and specific ridge topography has been completed. An invited review paper on ocean mixing has been written for the sixtieth anniversary special issue of the Japanese Journal of Oceanography. Other completed papers on related topics include an encyclopedia article on internal waves, a book chapter in a general fluid dynamics survey published by Cambridge University Press, and an article and co-convenor's meeting summary for the ONR-sponsored Hawaiian Winter Workshop on stirring and mixing in the stratified ocean.

A paper on the effects of entrainment on hydraulic flows has been completed and accepted for publication.

Acoustic, turbulence, and CTD data from the June, 2000, Knight Inlet cruise should permit a check on theories for backscatter from turbulence and zooplankton.

RESULTS

Earlier data collected with a 300 kHz ADCP in central Juan de Fuca Strait show a clear signal of vertical Reynolds stresses at neap tides (Figure 1). The stresses are clearly related to a decrease in the background Richardson number associated with an upstream release of stratified water, but are not easily related to the mean flow via a simple eddy viscosity. A cross-strait circulation is also apparent, as expected from a divergence of the Reynolds stress, but the relationship is not a simple local one.

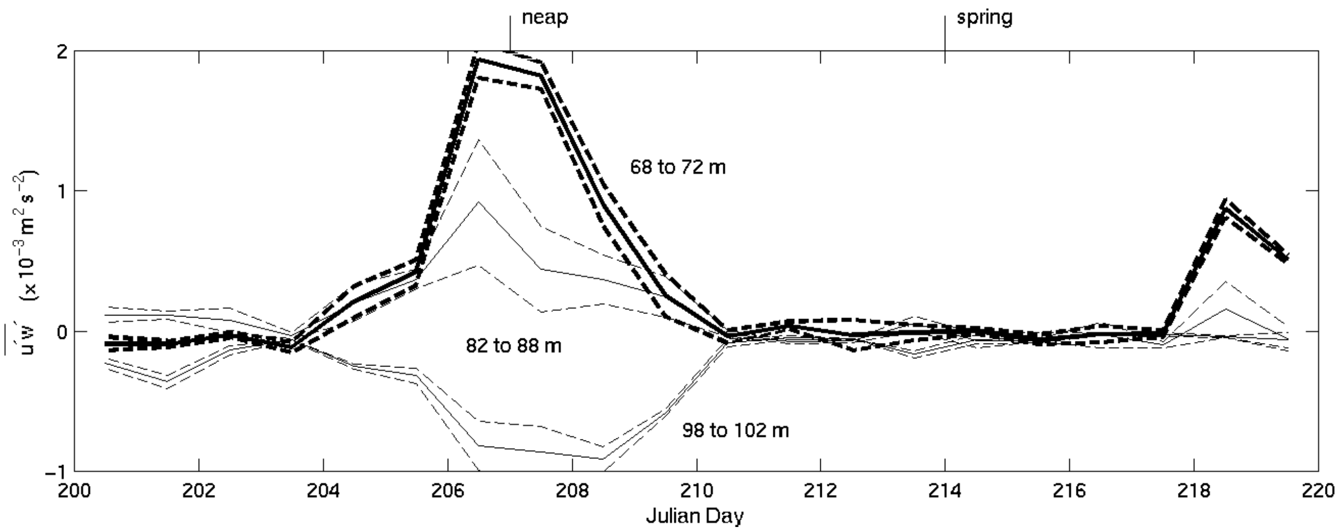

Figure 1.The Reynolds stress, or vertical momentum flux, at depths of 70, 85 and 100 m in Juan de Fuca Strait in summer 1996, is negligible except for a dramatic burst for a period of about 3 days centred on neap tides.

A study of internal tide generation in the deep ocean shows that most of the energy flux goes into low modes which are not susceptible to local shear instability and are also more likely to return to the sea floor, after reflection at the sea surface, rather than lose their energy via wave-wave interactions. Some energy is lost at each encounter with the sea floor, but most will radiate over O(1,000) km and hence contribute mainly to mixing remote from the generation site. The energy flux per square meter from two locations in shown in Figure 2. We have also shown that for mid-ocean ridge topography, critical slopes are only achieved at small scales which do not greatly influence the energy flux.

Our study of the role of entrainment in hydraulic flows has shown that, like friction, it tends to push a flow towards criticality, though its effect on layer thickness can be very different.

An earlier theoretical result on bubble size spectra in the upper ocean, predicting a –10/3 power law, seems to be getting some support from recent observations by Grant Deane and Dale Stokes at Scripps Institution of Oceanography.

On a very different topic related to a general interest in ocean energy issues, I have pointed out that tidal power generation by continuous flow requires the development of a significant head differences, and so is really no different from standard schemes. Nonetheless, it is possible to generate significant power while still preserving much of the normal tidal range, as may be desirable for aquaculture and pollution control.

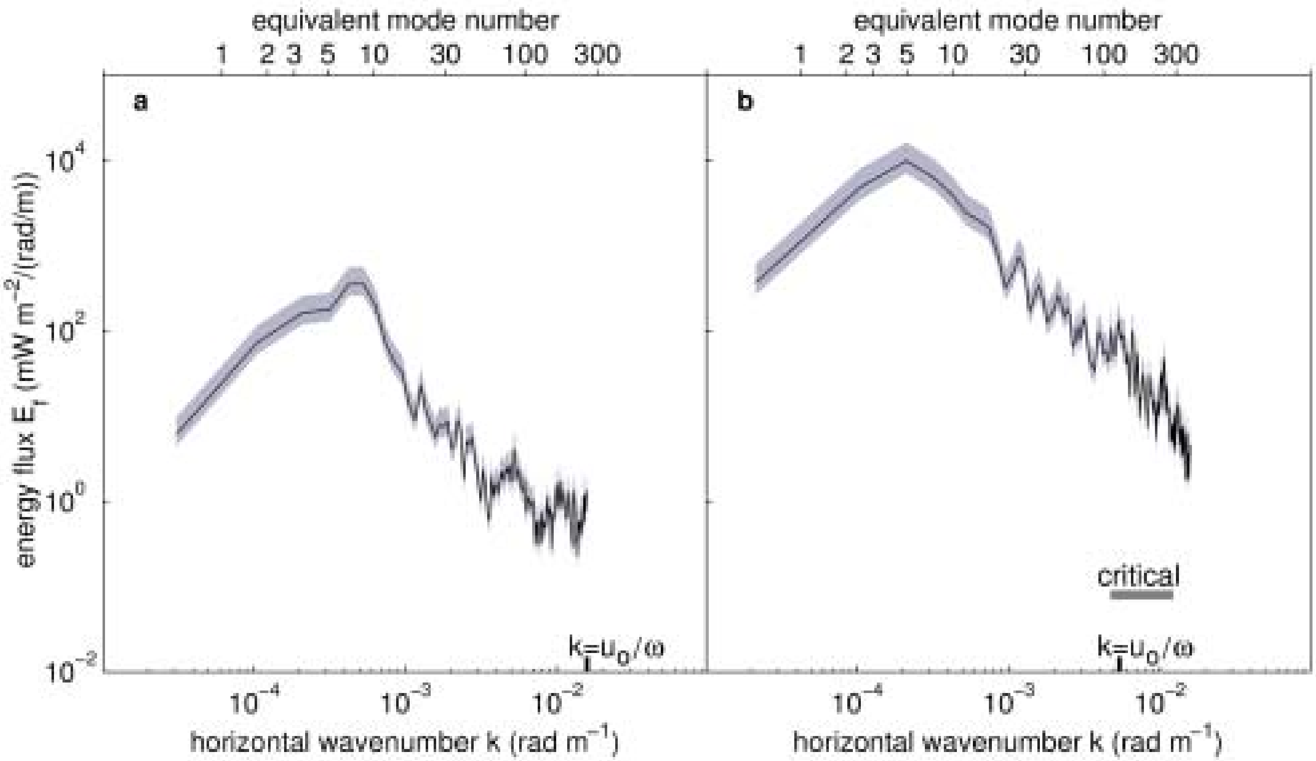

Figure 2. Internal tide energy flux spectra as a function of the horizontal wave number (and equivalent vertical mode number) for (a) the East Pacific Rise and (b) the Mid-Atlantic Ridge. The spectra are red, showing that most of the flux goes into low modes. The wavenumber equal to the tidal excursion is marked and is approximately 0.01 radian/m. The slope also becomes critical at about this scale for the Mid-Atlantic Ridge, but is still subcritical for the East Pacific Rise.

IMPACT/APPLICATIONS

Our results on internal Reynolds stresses in stratified flows have implications for the modeling of internal friction in estuarine and other models, and show the importance of 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 study should help to clarify the importance and dominance of mixing remote from the generation site as well as providing accurate estimates of the energy flux from real topography.

The new results on hydraulic flows with entrainment could provide an intuitive basis for understanding real exchange flows.

The earlier results on bubble sizes will provide a useful input to models of air-sea gas exchange and acoustic propagation in the upper ocean.

Ongoing analysis of results from our 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 behaviour.

The proceedings of the 2001 ‘Aha Huliko’a, which I con-convened, should reach a wide audience interested in the interaction of stirring and mixing processes in the ocean.

TRANSITIONS

We are collaborating with Professor Parker MacCready and others at the University of Washington.

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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