A Study of the Structure of the Near-Coastal Zone Water Column Using Numerical Simulations

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LONG-TERM GOALS

Our long-term goal is to understand how flows in near-coastal zone (20m to 100m) respond to a variety of forcing mechanisms including tidal pressure gradients, surface waves, surface heating and cooling, surface wave-bottom current interaction, and tidally generated bottom boundary currents. Because the nature of this response varies throughout the water column and depends strongly on the non-linear coupling of stratification, turbulence and flow structure characterizing the structure of the water column in this environment is a very difficult field measurement task.

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14. ABSTRACT
Our long-term goal is to understand how flows in near-coastal zone (20m to 100m) respond to a variety of forcing mechanisms including tidal pressure gradients, surface waves, surface heating and cooling, surface wave-bottom current interaction, and tidally generated bottom boundary currents. Because the nature of this response varies throughout the water column and depends strongly on the non-linear coupling of stratification, turbulence and flow structure characterizing the structure of the water column in this environment is a very difficult field measurement task.

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OBJECTIVES

It is possible to gain some insight into the physics, and into our ability to model or parameterize the physics, by looking at a more idealized version of this problem using large eddy numerical simulations (LES). We are performing simulations of the mixing processes in the upper layer of the near-coastal, and deeper, using a periodic channel as the computational domain. Benefits of using numerical simulations, as compared to laboratory or field experiments, is the relative ease with which information about the turbulence can be extracted from the flow and the control over the external variables. The study has two fundamental goals: (1) Developing deeper understanding of the interaction between various physical mechanisms that affect the dynamics of the upper mixed layer in the near-coastal ocean and the deep ocean; and (2) Developing improved parameterizations of these processes for use in large eddy simulations (LES) and Reynolds-Averaged Navier-Stokes (RANS) models to be used in modeling on the larger scales.

APPROACH

The LES technique is employed to solve the Navier-Stokes equations for stratified turbulent channel flow numerically. A vortex forcing term has been added to simulate Langmuir circulations. The code employs the dynamic eddy viscosity model of Germano *et al.* (1991) with Lilly's (1992) least squares modification. This code, which was originally developed and implemented on the 400-node Intel Paragon XP/S supercomputer at SDSC by Garg *et al.* (1994), has been modified both to be portable to extant parallel computing platforms and to account for the additional physical phenomena we wish to examine. The code is currently running with a 128x256x128 grid on our local 40-node Compaq/Alpha Beowulf cluster (http://fluid.stanford.edu/baywulf /baywulf.html), and we are in the process of porting the code to the 260-node IBM Netfinity Linux Supercluster at the Maui High Performance Computing Center (http://www.mhpcc.edu/doc/huinalu.html).

WORK COMPLETED

Following Zhou (1999), we added the Craik-Leibovich vortex forcing term to the momentum equations in order to simulate Langmuir circulations. Preliminary runs of the channel flow code show the development of Langmuir cells in the absence of stratification. We also added the ability to vary the thickness of a thermocline density profile in the channel. Due to increases in computing power, higher Reynolds number ($Re_\tau = 720$) cases have also been completed to complement the $Re_\tau = 360$ cases. These modifications to the code will allow us to examine the interactions among Langmuir circulations, stratification, and smaller scale turbulence. We have also continued to investigate possible relationships between constants used in turbulence closure models and local turbulence parameters such as turbulent Froude number (Fr_t) using both the results from the DNS simulations reported in Holt et al (1992) and Shih et al (2000).

RESULTS

We ran numerical simulations of stratified channel flows for a number of different flows, varying the strength of the stratification, the relative position of the stratification in the water column, and the type of density boundary conditions (either constant temperature or zero flux). We were able to compute planar averaged statistics for these flows which are typically characterized by a relatively well-mixed, lower boundary region where the turbulence is quite vigorous; a thermocline region where the turbulence is strongly affected by the buoyancy forces; and an upper mixed layer which is separated from the lower boundary by the thermocline. The nature of the stratified turbulence is very similar to that seen in other flows. This is shown in Figure 1 where time-averaged mixing efficiencies (flux Richardson number Ri_f) for the $Re_\tau = 360$ and 720 channel flow cases are shown. As can be seen from the plot the peak mixing efficiency is about 0.2 , and at high turbulence activity number ($\varepsilon/\nu N^2$) it decreases to zero. There are also "-ve" mixing efficiencies indicating the presence of counter-gradient fluxes in part of the flow.

We also continue to examine the results from the direct numerical simulations performed by Shih et al. (2000), and Holt et al. (1992). As reported in Ferziger et al. (2002), we are interested in developing modifications to existing turbulence parameterizations (such as k-e and Mellor-Yamada) by incorporating the results of our analyses of our simulations. In Figure 2 we show the relationship between the normalized total diffusivity and $\varepsilon/\nu N^2$. The plot is characterized by three regions. In the first region ($\varepsilon/\nu N^2 < 7$) the normalized total

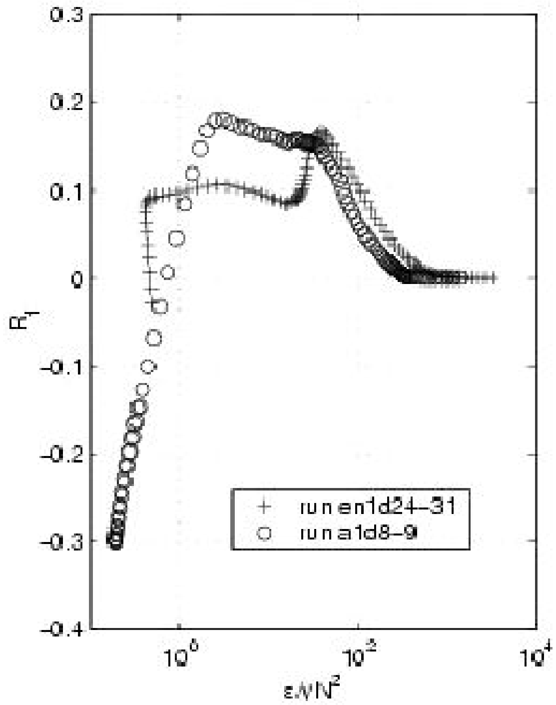

Figure 1: Plot of time-averaged flux Richardson number Ri_f versus turbulence intensity $\varepsilon/\nu N^2$ for Re_τ = 360 and 720 cases.

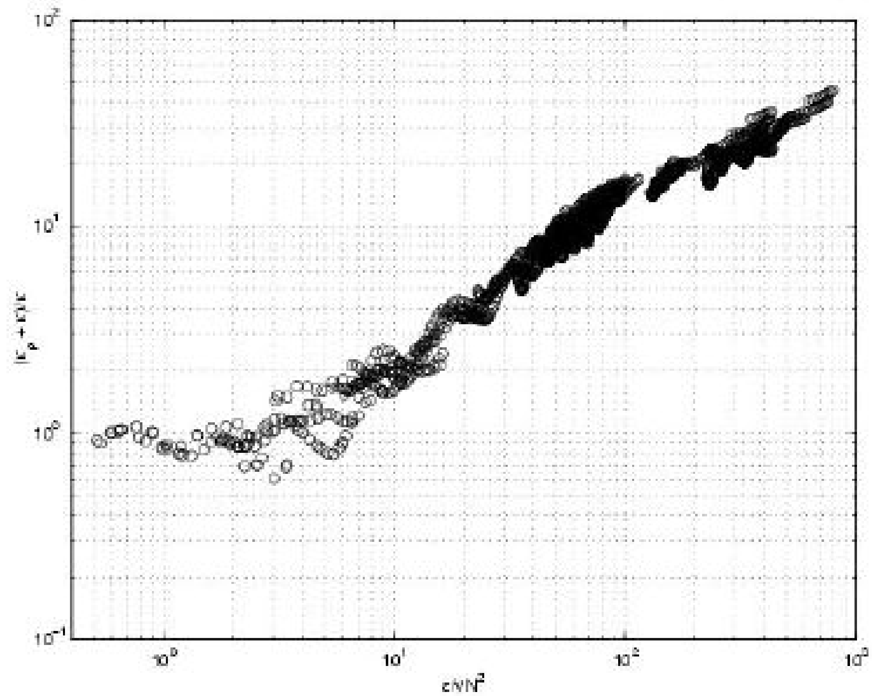

Figure 2: Plot of total diffusivity normalized by molecular diffusivity $(\kappa_\rho+\kappa)/\kappa$, versus the turbulence intensity paramter $\varepsilon/\nu N^2$.

diffusivity decreases to the molecular limit of unity. In the second region ($7 < \varepsilon/\nu N^2 < 75$) the normalized diffusivity increases linearly to a value of about 10x molecular diffusivity. For values of $\varepsilon/\nu N^2 > 70$ the normalized diffusivity increases linearly as well but at a different rate. The normalized diffusivities are slightly below the molecular limit of unity at $\varepsilon/\nu N^2 < 7$, where there is evidence of counter-gradient fluxes; thus, modelling diffusivity (using gradient flux or mixing length approaches) is expected to be problematic at these lower values of $\varepsilon/\nu N^2$. Figure 2 further suggests a working definition of an energetic regime to be when the diffusivity is about ten times the molecular value, or when $\varepsilon/\nu N^2 > 75$.

IMPACT/APPLICATIONS

The simulations completed demonstrate the intrinsic value of DNS and LES in that it allows us to calculate each term in a model or parameterization of the extant physics. Evaluation of existing turbulence closure models or commonly used sub-grid-scale parameterizations is therefore a lot more complete than with experiments alone. Our simulations of the channel flows are the first important step in developing a code for studying the evolution of the density structure of the water column in the near-coastal ocean. Once completed this code will be a valuable research tool for use in conjunction with field work currently underway involved in measuring flowfields in the near-coastal ocean.

TRANSITIONS

The numerical databases developed have been analyzed by the PI's in other research projects and the data has been used by researchers at other institutions. For example Diamessis and Nomura at UCSD are using the data from the simulations of Shih *et al.* (2000) to further examine the interaction between vorticity and rate-of-strain in stratified turbulence. In addition, Barry and Ivey at the Center for Water Research at the University of Western Australia are using the data to look at parameterizations of turbulent length scales and buoyancy flux in stratified flows.

RELATED PROJECTS

Shear Production and Dissipation in a stratified tidal flow - ONR - (Monismith PI). Our field work includes work on stratified tidal flows in which we are making Reynolds stress measurements using broad-band ADCPs

An Experimental Study of a Breaking Interfacial Wave - NSF- (Koseff PI). In the laboratory we are performing experiments in an attempt to measure the mixing associated with a breaking internal wave at a stratified (two-layer) interface using the wave-generation technique of Rapp and Melville. In this work we are measuring the mixing efficiency associated with such an event.

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