Large Eddy Simulations Of Hydraulically-Controlled Exchange Flows

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LONG-TERM GOAL

My long term interests are in identifying important mixing processes in the coastal ocean and understanding their interaction with mesoscale processes.

OBJECTIVES

The objectives of this program are to better understand the influence of friction and mixing at internal hydraulic controls. Inviscid theory makes predictions which have proved difficult to apply quantitatively and we seek to understand if neglect of viscosity and diffusion can alleviate these problems.

Another aspect of my work is to finalize acoustic doppler current profiler (ADCP) datasets from the Coastal Mixing and Optics (CMO) program.

APPROACH

The approach adopted by myself and Dr. Kraig Winters has been to develop a large eddy simulation (LES) of a contraction control and compare the simulated results with observations from the central contraction of the Bosphorus Straits. The model is first validated with a sequence of tests, then applied to a simple contraction control and the results compared with predictions from inviscid theory (e.g. Armi and Farmer, 1986). The physical domain of the simulation will then be constructed to grossly represent the central contraction in the Bosphorus and the results compared and contrasted with detailed observations collected by Dr. Michael Gregg. A combined model/observation analysis should lead to a more complete understanding of viscous and diffusive effects on an internal hydraulic control.

I also accompanied Dr. Ledwell's group during the CMO cruises to operate the shipboard ADCP to evaluate its performance and help track the dye injection.

WORK COMPLETED

The LES is now up and running in two geometries, either a pure contraction (no depth variations in the geometry) or a pure sill flow (no cross-channel variations in geometry). A series of validation runs have been completed and a manuscript documenting the model has been submitted (Winters et al, submitted).

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A series of runs varying the flux ratio for a fixed geometry have been analyzed as two and three layer flows to permit comparison with existing theory. A comparison of these results with two-layer inviscid theory has been carried out as an initial investigation of the effects of viscosity and diffusion on internal hydraulic controls. A manuscript describing this study has also been submitted (Winters and Seim, submitted).

Analysis of Gregg's observations from the Bosphorus continues. A two and three-layer decomposition of the velocity and density field has been devised to facilitate comparison between the simulation output and observations. Conversion of the acoustic imagery into calibrated signals is also underway. Gregg is still processing the dissipation profiles (this has proved quite difficult), so no analysis of these observations has been possible.

The 1997 ADCP data from the CMO cruises has been finalized and distributed, and an initial analysis of the 1996 and 1997 datasets presented at the 1998 Ocean Sciences Meeting.

RESULTS

The LES comparison with two-layer inviscid theory suggests two principal results. The presence of interfacial friction alone (i.e. no bottom friction) does not qualitatively alter the hydraulic solutions in that two hydraulic control points define a subcritical flow region, bounded by supercritical flow regions, meeting the Armi and Farmer 1987 criterion for a maximal exchange flow. The interface, however, grows to occupy a significant fraction of the water depth, carries a significant fraction of the layer transport (as much as half), and leads to recirculation (i.e. property transport is not unidirectional). These results would pertain to deep channels where the pycnocline is far removed from the bottom.

The introduction of bottom-friction (e.g. a shallow system) leads to a qualitative shift in the nature of the solution. We were unable to generate a flow configuration with two control points, and hence the solution in this case is not a maximal exchange solution. Instead, the flow resembles the submaximal exchange solution of Armi and Farmer 1986, in which the interface is at mid-depth to one side of the contraction and deflects upward on the other side. The LES is forced in such a way, however, that we do not flood the controls by altering the reservoir conditions, which Armi and Farmer 1986 describe as the way in which submaximal exchange flows are generated. The implication is that bottom friction alone can shift the flow regime to a submaximal state without the need for a change in a boundary condition of the system. Said another way, submaximal conditions can be locally induced by the presence of bottom friction.

The nature of flow instabilities also changed. In runs with only interfacial friction, small wave packets occasionally were generated in the supercritical regions of the flow, but the instabilities were minimal and a near steady-state flow was readily achieved. With bottom friction, the interface to the side which deflects was unstable, and a progression of large shear instabilities was shed, and only a quasi-steady state was realized. The majority of the upper-layer transport is carried in the interface downstream of the contraction. Importantly, in the averaged fields supercritical conditions existed over a very small extent of the domain, and would be essentially unobservable with conventional measurement systems.

An analysis of three parallel transects collected in the central contraction of the Bosphorus suggests that the flow there resembles the submaximal exchange solution. In Figure 1 the thickness of the interfacial layer grows from roughly 15 m north of the contraction to 35 m to the south of it, and rises from being centered near mid-depth north of the contraction by more than 20 m south of it. This is very different from the maximal exchange solution in which the interface would thicken to both the north and south of the contraction, and rise to the south and fall to the north of the contraction.

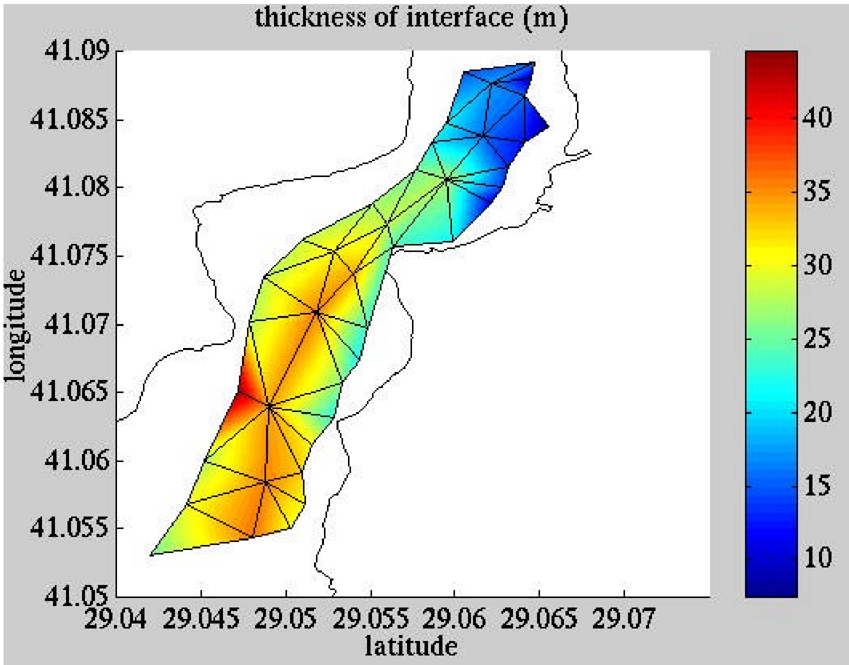

Figure 1. Thickness of the interface through the central contraction of the Bosphorus, determined from three parallel transects collected by Gregg. Note the thickening only to the south, and the thinning of the layer near the coasts.

Also apparent in Figure 1 is cross-channel structure in the interface, which is thickest at mid-channel and thins near the shores. Another set of LES runs with a geometry more similar to the Bosphorus will be used to explore the three-dimensionality of the hydraulic control.

Analysis of the CMO ADCP indicates very different flow regimes in 1996 and 1997. In 1996 a stable 40 cm/s westward jet, roughly 10 km in width, straddled the 65m isobath, and dominated subtidal shear dispersion. In 1997 intrusions from the shelf break front dominated the subtidal flow field and meso-scale (10-20 km) eddy-like structures dominated shear dispersion.

IMPLICATIONS/APPLICATIONS

The importance of the interfacial layer in property transport has previously been suggested by Bray et al. (1995) in their analysis of observations from Gibraltar, and our LES results confirm and generalize these ideas. We have followed their suggestion of a three-layered analysis and find this to be a useful simplification of the density field. This treatment may lend itself to simplified modeling. Indeed, Cudaback (1998) has already pursued such an approach in studying the Columbia River Estuary. A fruitful line of investigation may be exploring parameterizations of the entrainment by the interfacial layer that best approximate observed conditions.

Further, a drawback of the existing inviscid hydraulic theory is the lack of quantitative agreement with observations. Broad regions of supercritical flow are seldom, if ever, observed in nature systems. Our finding that bottom friction can shift the solutions to a submaximal exchange in which no extensive regions of supercritical flow exist may explain our inability to find significant regions of supercritical flow in natural systems. The inability to find quantitative agreement and theory makes inferences about exchange rates based on the theory questionable.

The broadband ADCP aboard *R/V Oceanus* functioned reasonably well and did provide temporal and spatial resolution superior to a narrow band ADCP. In rough weather the system degraded noticeably, however. The shift in circulation regimes between years should help explain variations in dye dispersion and adds to our appreciation of the variety of circulation modes supported by the coastal ocean.

TRANSITIONS

The LES is being used to a graduate student of Winters. The notions of submaximal exchange are being explored by Gregg as a possible explanation of the structure along the length of the Bosphorus. These ideas should be of interest in other systems in which bottom friction is expected to be dynamically important, such as shallow systems.

The ADCP datasets from the CMO cruises have been distributed to Ledwell and co-PIs and have been shared with other CMO investigators. The software developed for working with both the processed and raw broadband ADCP data is being used by various other groups.

RELATED PROJECTS

Winters and I have been working together on the model development, and his report provides a more thorough description of the numerical scheme. Gregg has generously shared his observations (which Winters and I helped collected) and we are in contact about the analysis and interpretation of the full dataset.

Ledwell, Duda and Oakey were the co-PIs on the cruises in which I participated, and they are making use of the ADCP data in their analyses.

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