Subgrid Scale Modeling For LES Simulation of Flow In A Turbulent Bottom Boundary Layer

Manhar R Dhanak
Department of Ocean Engineering
Florida Atlantic University
777 Glades Road, Boca Raton FL 33431.
Phone: 561-297-2827 fax: 561-297-3885 email: dhanak@oe.fau.edu

Donald Slinn
Department of Civil and Coastal Engineering
University of Florida
Gainesville, FL 32611-6590
Phone: 561-297-2827 fax: 561-297-3885 email: slinn@coastal.ufl.edu

Oleg Zikanov
Department of Mechanical Engineering
University of Michigan
Dearborn, MI 48128

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http://www.oe.fau.edu

LONG-TERM GOAL

The long-range goal of this work is to develop improved understanding and predictive capability for shallow water dynamics.

OBJECTIVE

To develop a subgrid scale model for large eddy simulation (LES) of the flow in a turbulent stratified flow in shallow water, based on parameterizations determined from field measurements, direct numerical simulation (DNS) studies, and theoretical considerations. The aim is to provide accurate characterization of energy dissipation and Reynolds stress close to surface and bottom boundaries in a way which can be easily incorporated in predictive, coarse-grid models of flow in the littoral zone under a variety of conditions. This work is complementary to other ongoing ONR funded computational (Slinn) and observational (Dhanak) studies.

APPROACH

The work involves theoretical analysis, numerical computations, and comparison with field measurements. The primary research tools are three-dimensional DNS and LES models, which allow simulation of ocean dynamics in shallow water and surface boundary layers.

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WORK COMPLETED

- Large-eddy simulations of turbulent penetrative convection in shallow water caused by the passage of a cold air front have been completed. A paper "Turbulent convection driven by surface cooling in shallow water" by Zikanov, Slinn & Dhanak has been published: *Journal of Fluid Mechanics, 2002, vol. 464, 81-111.*
- The LES numerical model used in the first part of the project has been modified to include the effects of the Earth's rotation and wind stress at the water surface. The model has been applied to simulations of the turbulent Ekman layer near the ocean surface. Full-scale simulations of the neutrally stratified Ekman layer at different latitude have been carried out and analyzed. The results are reported in a paper entitled "Large-eddy simulations of the wind-induced turbulent Ekman layer" by Zikanov, Slinn and Dhanak has been submitted to *Journal of Fluid Mechanics*.
- In recent work, the role of an unsteady wind stress, both in magnitude and direction, on a turbulent Ekman layer, is investigated using LES model. Analysis of the flow characteristics as well as the temporal and spatial dependence of the eddy viscosity has been developed, highlighting the effect of the unsteadiness on modifying the depth of the Ekman layer. A paper, entitled "Effect of unsteady wind stress on the Ekman layer" by Barr, Slinn & Dhanak has been submitted to JGR.
- The effect of finite depth of a water column on the nature of the wind driven flow was determined using the LES model. The work has resulted in a MS thesis at FAU relating to wind-driven flow in shallow waters by Lionel Gurfinkiel, the student supported on the project.

RESULTS

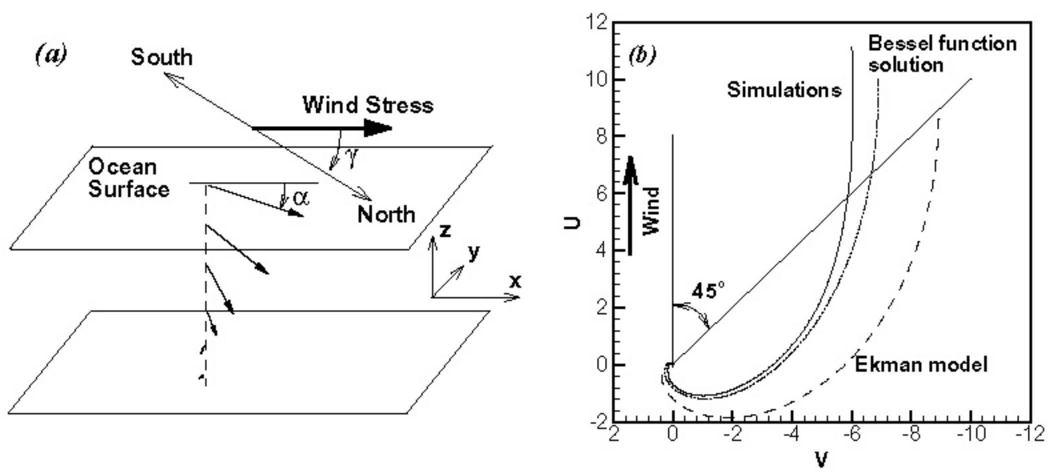

Figure 1.(a) Model geometry. (b) Time and horizontally averaged hodographs of the horizontal current.

Detailed results of the investigation of the effect of the unsteady wind stress on the turbulent Ekman layer (Figure 1) are reported in a paper submitted to JGR. We found that the phase averaged effective viscosity varies significantly across the layer (Figure 2), and that the simplified 1-D model agrees qualitatively with the full LES simulations. Since the simpler model contains no information about either the latitude or direction of wind stress, quantitative agreement cannot be expected, as shown in the case of steady wind stress. Turbulent bursts at times of minimum forcing, when the inertial current is weak are responsible for the transport of turbulent energy deeper into the water column.

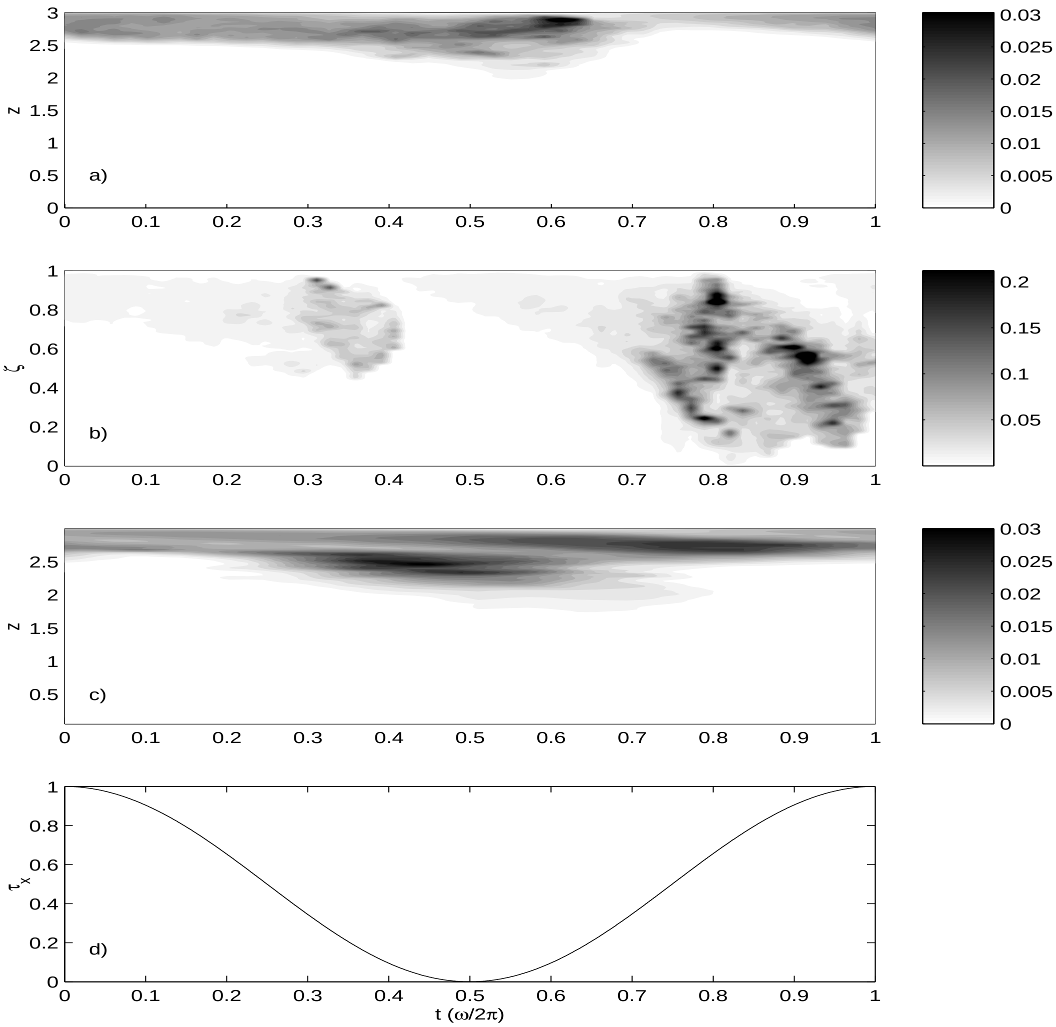

Figure 2. Phase averaged effective eddy viscosity for the varying amplitude cases. (a) $\omega = 0.5$, (b) $\omega = 1$, (c) $\omega = 2$, (d) applied wind stress.

With resonant forcing, this penetration leads to finite values of turbulent kinetic energy near the bottom boundary, leading to a numerical instability and the subsequent demise of the simulation. A resonant effect was found to occur in a case of off-resonant forcing (directional forcing with ω= 0.5). The relative transience of the wind stress appears in the discrepancy of the Ekman layer depth as measured by the mean current or the mean turbulent kinetic energy. This may help observationalists without available wind data. Future improvements on the model include allowing for density stratification and diurnal heating and cooling. With the improvements, it should become possible to model results obtained from other in situ measurements.

Detailed results of the investigation of the influence of the finite depth of the water column are given in a MS thesis at FAU. The characteristics of the mean velocity profile and of mass transport are determined. The variability of the velocity profile in the hodograph plane for various depths is shown in Figure 3. For dimensional depths corresponding to 20, 40 and 60 m water depths and a steady wind of 10m/s, surface deflections of 46^0, 31^0, and 29^0 due to the effect of the Coriolis force are implied by the simulations. Whereas in deep water the mass transport is effectively at right angle to the wind direction, the latter angle is reduced by around 10^0 for water depth of around 20m.

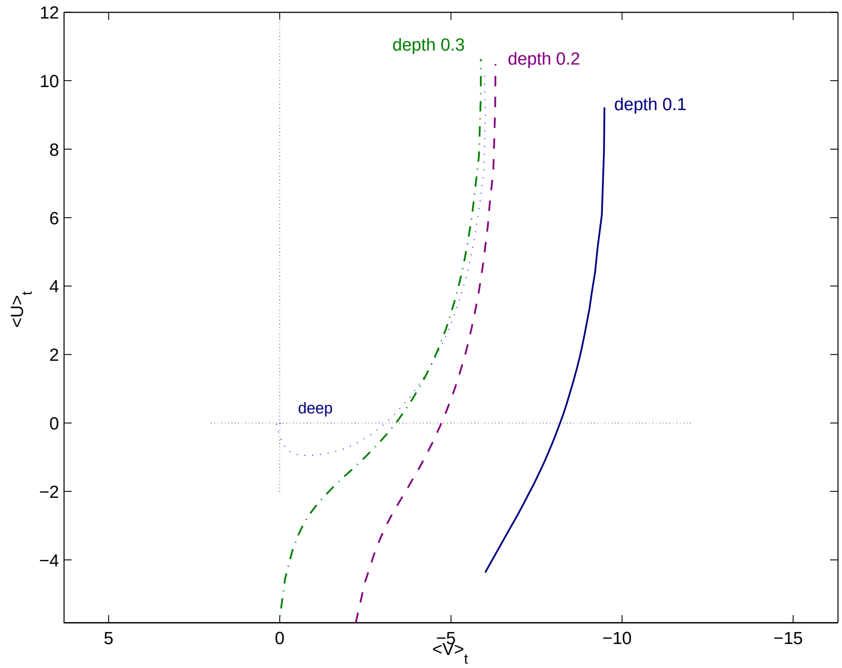

Figure 3. Velocity hodograph of the simulated flows for shallow water with changes of the depth and simulated flow in deep water

IMPACT/APPLICATIONS

An important potential benefit of our work for the ocean community is that it serves to develop and validate an accurate and efficient LES model for oceanic turbulence. Furthermore, our work contributes to better understanding of fundamental properties of such an important phenomenon as the turbulent Ekman layer near the ocean surface.

TRANSITIONS

The LES code that has been developed will allow us to consider several types of problems, such as developing mixed layers in response to unsteady wind fields, combined influences of shear and wind effects and other factors of importance in flows in the littoral zone.

RELATED PROJECTS

The work is carried out in conjunction with field measurements under grant N00014-96-1-5023.

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