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

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LONG-TERM GOAL

The long-term goal of this work is to develop an accurate and efficient LES (large-eddy simulation) model of turbulent flows in oceanic boundary layers.

OBJECTIVES

The major objectives to be achieved are:

(1) Acquire better understanding of specific properties of oceanic boundary layers, particular attention being paid to statistics of small-scale coherent structures and their adequate representation by subgrid-scale (SGS) models.
(2) Implement the Smagorinsky and dynamic SGS models and validate them for oceanic boundary layers through comparison with direct numerical simulations (DNS) and autonomous underwater vehicle (AUV) field data.
(3) Develop and test a SGS model capable of accurate parameterization of the effects of small-scale coherent structures.

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.

WORK COMPLETED

1) 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 submitted and is currently under consideration in the *Journal of Fluid Mechanics.*
2) 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. A series of test calculations have been performed to validate the model and identify the model parameters (numerical resolution and

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14. ABSTRACT
The long-term goal of this work is to develop an accurate and efficient LES (large-eddy simulation) model of turbulent flows in oceanic boundary layers.

15. SUBJECT TERMS

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the dimensions of computational domain) sufficient for adequate representation of the actual ocean flow. Full-scale simulations of neutrally stratified Ekman layer at different latitude are currently under way.
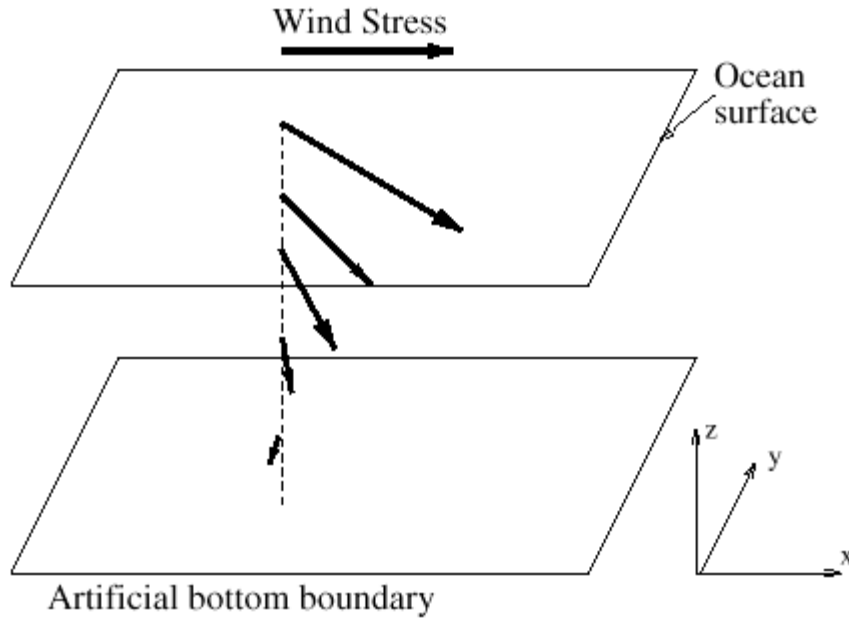

Figure 1. Schematics of the model problem

RESULTS

The classical problem of a turbulent Ekman layer maintained near the ocean surface by a steady wind is approached using the method of large-eddy simulation (LES). We consider the flow in a horizontal layer confined between two infinite stationary planes (see Figure 1). The flow is assumed homogeneous in both horizontal directions so that periodic boundary conditions can be applied. The distance between the upper and lower boundaries and the horizontal dimensions are assumed large enough to minimize the impact of the boundary conditions at the bottom and at the periodic boundaries. The flow is generated by a constant wind shear stress applied at the upper surface. The fluid is considered to be neutrally stratified at this phase of the investigations.

Since the typical Reynolds number of the actual ocean flow is very high, we do not attempt to resolve the viscous and diffusion boundary layers near the upper surface. Instead, the limit of large *Re* is considered. Molecular viscosity is neglected in the equations. The surface boundary conditions are formulated in terms of momentum fluxes at a free surface.
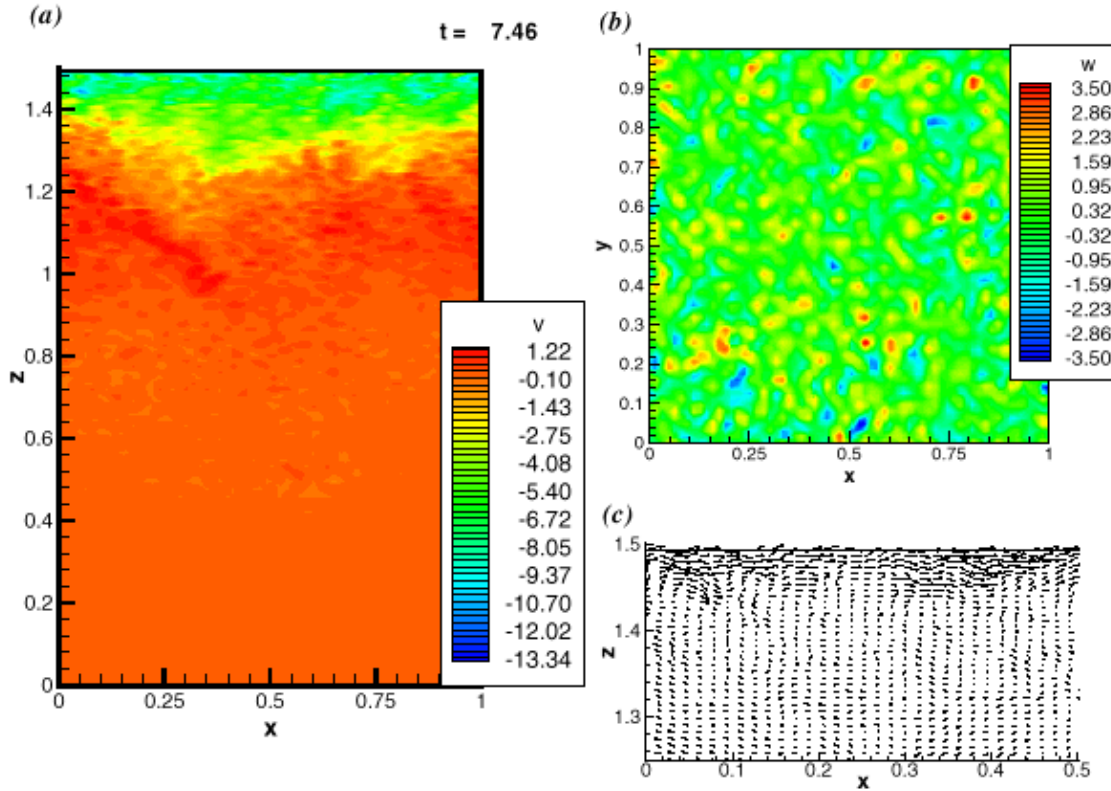
Figure 2 An example of the velocity field calculated in the LES of the turbulent Ekman layer. (a) Distribution of the v-velocity component in the vertical cross-section at $y = L_y / 2$, (b) distribution of the vertical velocity component in the horizontal cross-section at $z = L_z - 0.0675$, (c) projections (u, w) of the velocity vectors on the vertical plane at $y = L_y / 2$ (only a part of the cross-section is shown).

A standard version of the dynamic subgrid-scale model (Germano *et al* 1991 and Lilly 1992) is used in the LES. It has been found that the numerical model with the resolution $N_x \times N_y \times N_z = 64 \times 64 \times 120$ and the size of the computational domain (non-dimensionalized with turbulent length scales $L = u_* / f$) $L_x \times L_y \times L_z = 1 \times 1 \times 1.5$ is sufficient to accurately represent the flow properties.

In the result of the computations, the spatial structure and the statistical properties of the flow have been revealed. The simulations allowed us to revisit the classical Ekman effective viscosity model and to determine whether the model should be corrected based on the variability of the effective viscosity with depth. The calculations confirmed the conclusion first reached in the theoretical analysis by Rossby & Montgomery (1935) that the depth variability of the viscosity coefficient does not impose any significant impact on the mean flow. It has been found that the time-averaged vertical profiles of the velocity components obtained in the calculations are in striking agreement with the classical Ekman profile.

An example of a fully developed turbulent flow field is shown in figure 2. The simulations have not revealed any persistent large-scale coherent structures in the flow. Further details will be given in a journal publication under preparation.

A comparison between the numerical results AUV-based field observations (grant N00014-96-1-5023) will be made to determine the accuracy of the model and, if appropriate, to suggest modification of the subgrid-scale model.

IMPACT/APPLICATIONS

An important potential benefit of our work for 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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PUBLICATIONS

Zikanov, O., Slinn, D. N., & Dhanak, M. R (2001) "Turbulent convection driven by surface cooling in shallow water," submitted to *Journal of Fluid Mechanics*.