J 2.5 PRESSURE, VORTICITY AND VORTICES ASSOCIATED WITH SCALAR MICROFRONTS IN A LARGE-EDDY SIMULATION OF CANOPY FLOW

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1. Introduction

Many studies in the literature have focused on the occurrence and behavior of scalar microfronts in canopy flows. A scalar microfront is a tilted high scalar gradient region, which is characterized by a strong downward sweep motion upstream and an upward ejection motion downstream.

The study of pressure, vorticity and vortices associated with scalar microfronts in canopy flow has been impeded by limited experimental data. It is very desirable to conduct a numerical simulation - large-eddy simulation (LES) specifically, in which pressure is obtained by solving a Poisson equation and vorticity is derived from the curl of the velocity vector. Vortices can be identified based on pressure and vorticity.

2. Numerical simulation

The LES model used in this study was created initially by Moeng (1984) to model atmospheric boundary layer turbulence, and Patton (1997) extended it to model canopy drag. The domain is 96x96x30 grid points, with a grid space of 2m in each direction. The canopy occupies the lowest 1/3 of the vertical (*z*) domain. The bottom boundary is a non-slip wall, while the upper boundary layer is treated as a frictionless lid. Periodic boundary conditions are applied in the streamwise (*x*) and crossstream (*y*) directions. The canopy is horizontally uniform with a vertically varying leaf area density. A passive scalar is released from the canopy at a constant rate.

3. Theories

It is theorized that locally low pressure is predominantly associated with large vorticity, and locally high pressure is predominantly associated with high flow deformation. A physical explanation for the relation between locally low pressure and large vorticity is that they can both exist in a vortical structure, in which the large vorticity is a characteristic of a vortical motion and the low pressure provides a centripetal force for the vortical motion. To identify and analyze the vortices that occur in the LES, the low pressure method is applied.

4. Results and Discussion

Pressure

Broad high pressure regions, which are centered approximately at the intersections of scalar microfronts and the canopy top, are a very consistent feature of scalar microfront systems. A composite scalar microfront system is shown in Figure 1, which denotes the average of many of the scalar microfront systems. The high-pressure zone is associated with a strong deformation velocity field.

Vorticity

The vorticity vector is calculated from the three-dimensional velocity field generated by the large-eddy simulation. The typical crossstream vorticity patterns in the vicinity of the scalar microfronts are illustrated in Figure 1.

Positive crossstream vorticity mainly appears in two regions in a scalar microfront system: 1)under the maximum streamwise velocity perturbation upstream of the scalar microfront and 2)above the minimum streamwise velocity perturbation downstream of the scalar microfront. Negative values of crossstream vorticity are observed 1)above the maximum streamwise velocity perturbation upstream of the scalar microfront and 2)under the minimum streamwise velocity perturbation downstream of the scalar microfront. Consistent streamwise

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vorticity and vertical vorticity patterns have also been observed, which are not presented here.

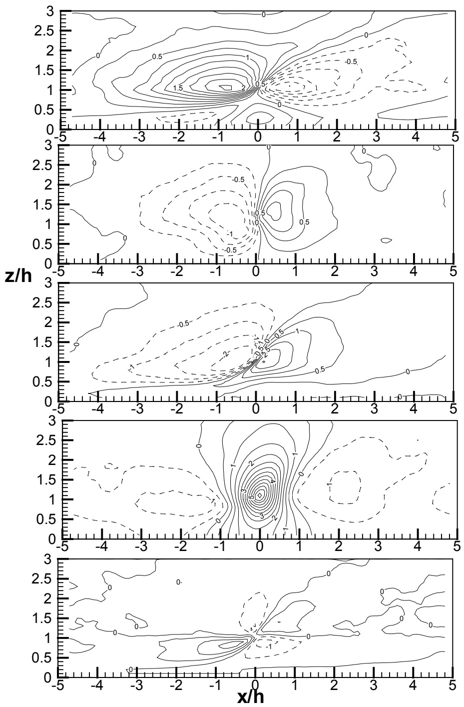

Figure 1 The conditional average of many scalar microfront systems, plotted on a vertical (*xz*) slice. From the top to the bottom plot are contours of normalized perturbations of : u'/u^*, w'/u^*, q'/q^*, $p'/(\rho_0 u^{*2})$ and $\omega'_y h/U_h$. The dashed contour lines are negative. Here, q represnts a scalar, ρ_0 is the air density, h is the canopy height and U_h is the average streamwise velocity at the canopy top.

Vortices

Three-dimensional vortices in the LES of canopy turbulence are identified using the low pressure method. Figure 2 illustrates isosurfaces of pressure at three different pressure magnitudes. By applying the low pressure method qualitatively, you can infer that these isosurfaces correspond with vortices.

Figure 2 illustrates many vortices, whose predominant characteristic is elongated or sausage-like. Hardly any of these vortices can be defined as quasi-streamwise vortices (which is aligned pre-dominantly in the streamwise direction) or as transverse vortices (which is aligned pre-dominantly in the cross-stream direction).

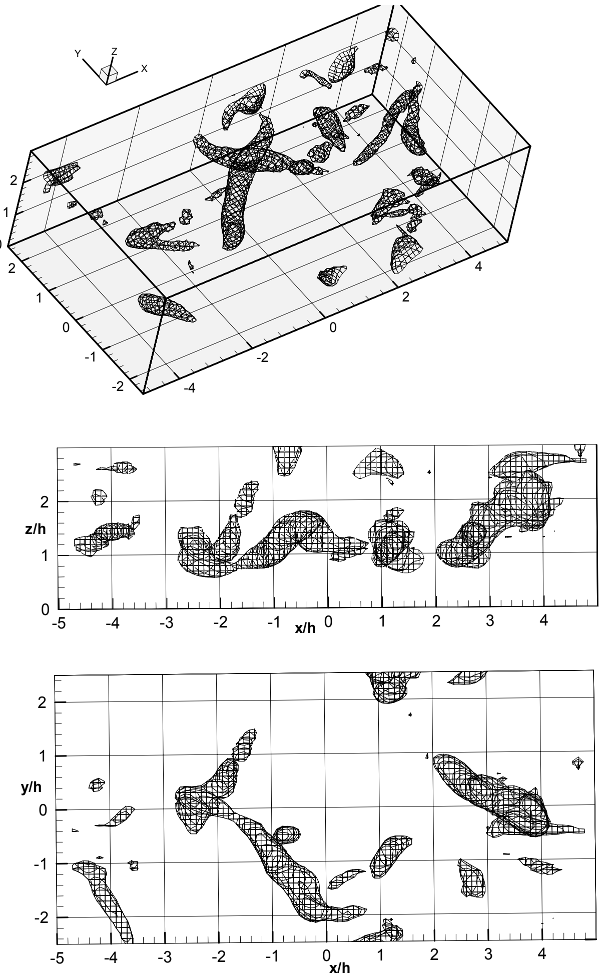

Figure 2 Vortices at one time step. The vortices are identified by the isosurfaces of pressure perturbations at -0.15 Pa. The top plot is a three-dimensional view. The middle one is the side view and the bottom one is the top view.

At the time step shown in Figure 2, there is a major scalar microfront, which is not shown in the figure but is centered at *x/h*=0 and *y/h*=0 where *z/h*=1. By examining approximately ten scalar microfronts and the vortices near them, a weak relation has been concluded between the vortices and the scalar microfronts.

Reference:

Moeng, C.-H (1984). A large-eddy-simulation model for the study of planetary boundary-layer turbulence. *J. Atmos. Sci.*, 41:2052-2062.

Patton, E.G. (1997). *Large-eddy simulation of turbulence flow above and within a plant canopy*. Ph.D. thesis, University of California, Davis.