9.7 NUMERICAL INVESTIGATION OF TURBULENCE STRUCTURES WITHIN AND ABOVE A CORN CANOPY USING LARGE EDDY SIMULATION

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Interaction between canopy and atmosphere results in complex structures of turbulence, which affects the transport mechanism of kinetic energy and momentum, as well as scalars such as water vapor, heat, carbon dioxide, pollen, and disease spores, etc. Interests in quantifying turbulence statistics and exploring large-scale coherent structures in plant canopies have led to a number of experimental and numerical investigations. This study aims to investigate turbulence structures within and above a corn canopy using large eddy simulation (LES). The computational results are compared with a recent field experimental data set from Particle Image Velocimetry (PIV) measurements and two other previous field measurements. Our PIV measurements were carried out in a corn field of 150 acres, located at the eastern shore of the Chesapeake Bay, Maryland, during July 2003. The measurements were performed at several different elevations, from just below canopy top up to 1m above the canopy.

Most previous LES considered forest canopies. Agriculture crops, such as corn, however, have been concerned with few works. The forest canopies were usually treated as a porous body of horizontally uniform area density in the numerical simulations. The heterogeneity of canopies, such as plant arrangement, was rarely taken into account. In these LES, the SGS closures are all based on parameterization of a length scale and a velocity scale. The model coefficient may critically change turbulence spectrum, and there is no general way to adjust it *a priori*. This paper studies turbulence structures addressing the heterogeneity of the corn canopy and using a dynamic Lagrangian SGS model which requires no *a priori* specification of the model coefficient.

The arrangement of the corn field where the PIV measurements were carried out is different from a normal one because it is double-row planted. Between the normal corn plant rows, an extra staggered row of corn is planted in order to increase corn production. We use two numerical approaches to simulate the corn canopy. One is called local-scale approach, which accounts for the heterogeneity of the corn canopy by resolving the arrangement of the corn plants. Each corn plant is simulated with a square force-cylinder in this approach. The other is called global-scale approach, which assumes the homogeneity of the corn canopy in a relatively larger computational box. The corn canopy is simulated with a horizontally homogeneous drag field.

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The predictions of the mean streamwise velocity profiles by both local- and global-scale approaches agree with the experimental data quite well. The vertical profiles are inflected around the canopy top, indicating the inviscid instability, and that turns out to play a critical role in canopy dynamics. The mean vertical profiles of the root—mean-square velocity profiles within the canopy suggest that there is some kind of “sloshing” motion in the deep canopy, which is not active in transporting momentum. The shear stress profiles decrease exponentially with depth within the corn canopy. The wall stress is negligible compared to that at the canopy top, indicating that the horizontal momentum is totally absorbed by the canopy. Above the canopy, the mean stress decreases to the zero value imposed at the top boundary of the computational domain, just like that in a standard surface-layer simulation. Above the canopy, the agreement of the predicted velocity skewness with the PIV data is fair. Below the canopy, there are significant differences between the local- and global-scale approaches.

The prediction of the mean correlation coefficient by the local-scale approach agrees with the experimental data better than the global-scale approach. Both numerical approaches predict a peak, -0.53 (local-scale) and -0.65 (global-scale), respectively, at z/h=0.7 within the canopy, which agrees with the measurement. This peak point implies that turbulence is the most efficient in transporting momentum at this elevation. This position is just above the inactive “sloshing” layer. Above the canopy top, the mean correlation coefficient is nearly constant, -0.4, close to the value of -0.32 for the forest. A quadrant analysis shows that sweep motion accounts for the largest contribution to the Reynolds stress within the canopy while ejection motion dominates above the canopy. The first and third quadrant events represent very weak motions of turbulence in the canopy flow.

One-dimensional energy spectra of the three components of velocity fluctuation with respect to the streamwise wavenumber are computed. Both numerical approaches predict the same slopes for the respective three components, which agree well with the PIV data and basically follow the Kolmogorov’s law for inertial-sublayer spectra. However, the slight deviation from the -5/3 slope may suggest a spectra short-cut effect within the canopy which results from the generation of wake kinetic energy by work against pressure drag. This effect is even amplified for the spectra within the canopy in the global-scale approach.