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BUDGET OF VELOCITY VARIANCES ACROSS A FOREST EDGE: A COMPARISON BETWEEN FIELD, WIND TUNNEL AND NUMERICAL SIMULATION STUDIES

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1. INTRODUCTION

Airflow experiences a drastic adjustment when it flows across a vegetation discontinuity, for example a forest edge. The fact that different velocity components take different rates in their adjustments has been recognized in many studies. As one example, by investigating the statistics of field data, Irvine et al. (1997) reported that the adjustment of streamwise velocity variance was faster than that of vertical velocity variance in the turbulent flow across a forest edge. They also suggested that the flow distortion at the edge was responsible for the different adjusting rates. In order to understand the controlling mechanisms of flow adjustment in the transition zone, budget analyses of velocity variances will be presented and a comparison of budgets between field, wind tunnel and numerical simulation studies will be made in this paper.

2. EXPERIMENTS

The field experiment was conducted at Harwood Forest, in Northumberland, England, while the wind tunnel was performed in the Oxford University environmental wind tunnel. Further details, for example instrumentation, tower arrangement and data acquisition in both field and wind tunnel, can be found in Irvine et al. (1997) and Morse et al. (2002).

A large eddy simulation (LES) was used to make the flow simulation. Details of the model can be seen in Yang et al. (2000). In order to make the required comparison, the appreciate parameters (canopy height of 7.5 m, leaf area index of 2, and a roughness length of 0.028 m for the ground surface) were chosen to match the field experiment by Irvine et al. (1997), which was also the data source in Morse et al. (2002).

All of the data presented from the LES were averaged in time and in the crosswind direction, and represent the motions of resolved scales unless otherwise specified. The computational domain in the LES extended to 20 H_c upstream of the edge. However, the data were truncated for clarification in plotting.

3. RESULTS

In the following sections, H_c will indicate the canopy height and u^* is the friction velocity at H_c level. The budget terms are normalized by $(u^*)^3/H_c$ from individual experiment. An overbar denotes an averaging operation while a prime is the departure from the mean value.

3.1 Streamwise Velocity Variance Budget

At canopy height the vertical shear production term is identified by all three studies as the major source of streamwise velocity variance and dominates the other terms (Figure 1). Starting at the forest edge shear production gradually increases in the transition zone and levels out at 12 H_c when equilibrium is achieved. Normalized values for this term from the three studies are of the same order of magnitude, with the largest value from the wind tunnel and the smallest value from the LES. Similarities also exist between the three experiments in vertical advection and horizontal convergence terms. Differences are apparent, however, in the turbulence transport terms (third order moments). While the field study reports small and positive but increasing values along the flow direction, the LES outputs show positive values within the first 10 H_c downwind from the edge but negative values after that location. The pressure redistribution term, which could not be measured in either the wind tunnel or the field, appears in the LES as the predominant sink term (not plotted). Like the vertical shear production term, the pressure redistribution term also picks up at the edge and gradually increases in magnitude along the flow direction.

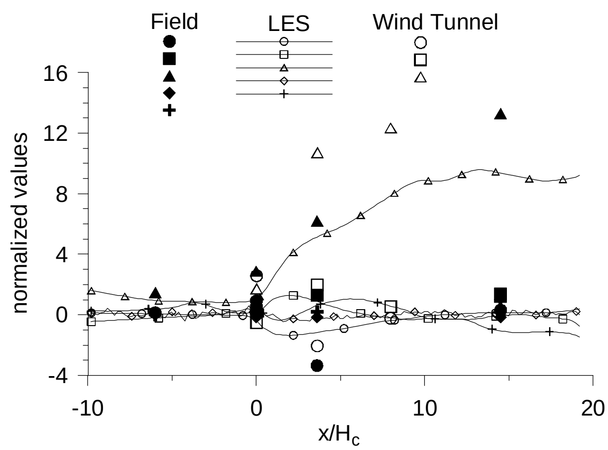

Figure 1. The budget terms of streamwise velocity variance at $z=H_c$. The edge is located at zero value of horizontal axis and positive values mean downstream. (circle: $-\overline{w}\frac{\partial \overline{u'u'}}{\partial z}$; square: $-2\overline{u'u'}\frac{\partial \overline{u}}{\partial x}$; triangle: $-2\overline{u'w'}\frac{\partial \overline{u}}{\partial z}$; diamond: $-\frac{\partial \overline{u'u'u'}}{\partial x}$; plus: $-\frac{\partial \overline{u'u'w'}}{\partial z}$)

The LES, with its high-resolution output, provides our investigation with budget terms of streamwise velocity variance within the canopy layer (not plotted). Below canopy height and at the forest edge, most of the budget terms, such as shear production, advection,

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pressure transport and canopy dissipation, increase rapidly and form a single pulse shape because of the discontinuity of the surface layer. After the pulses dissipate at about 3 H_c downwind from the edge, a number of significant terms, including shear production, turbulence transport, pressure redistribution and canopy dissipation, begin to increase in magnitude along the flow direction and finally level out in the equilibrium region. Generally the magnitude of these terms decreases with decreasing height within the canopy layer. Below canopy height and above 0.2 H_c, turbulence transport is the second major source term in addition to the shear production while the pressure redistribution and canopy dissipation are sinks. Although most of the terms are small at 0.2 H_c, the pressure redistribution term stands out as a positive term to balance the canopy dissipation.

3.2 Vertical Velocity Variance Budget

Regardless of magnitude, the budget terms at the canopy top for vertical velocity variance available from field and wind tunnel experiments show similar variations along the flow direction to those from the LES (Figure 2). Most of the terms are enhanced in magnitude due to flow distortion immediately behind the forest edge and relax to values close to zero after some distance from this edge. One interesting feature of the vertical convergence term from all three experiments is that it changes sign at about 6 H_c downwind from the edge. The only difference is that the LES exhibits a smaller magnitude than the other two studies. With its ability to solve the static pressure perturbations, the LES shows, at canopy height, much larger values for pressure redistribution and pressure transport terms than the above mentioned terms, with the former one as a source term to balance the latter one (not plotted). The pressure redistribution term does not change to a positive value until about 2 H_c downwind from the edge, and starts to increase and adjust to the new rough surface only after the sign switch. This is a little later than is the case for the major source term, shear production, for streamwise velocity variance, which starts to increase immediately at the edge.

Sharp variations of advection, pressure transport and drag dissipation are shown by the LES at the forest edge below canopy height (not plotted). This again indicates the flow discontinuity caused by the edge. The fact that the magnitudes of ‘sharp variations’ decrease as the height decreases suggests that the edge has the greatest effect on flow distortion in the top layers of the canopy. The drag-related term acts as a sink for the vertical velocity variance budget through the entire canopy layer. One interesting point is that pressure transport and pressure redistribution terms play opposite roles in the budget. While at 0.8 H_c and above, pressure redistribution acts as a source term and pressure transport term as a sink, at 0.6 H_c and below these two terms switch roles. This switch may suggest a decoupling of the flow between upper and lower layers of canopy.

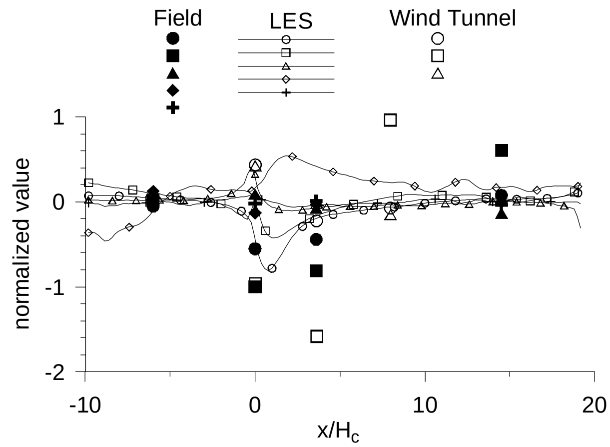

Figure 2. Same as Figure 1 but for vertical velocity variance. (circle: $-\overline{w}\frac{\partial \overline{w'w'}}{\partial z}$; square: $-2\overline{w'w'}\frac{\partial \overline{w}}{\partial z}$; triangle: $-2\overline{u'w'}\frac{\partial \overline{w}}{\partial x}$; diamond: $-\frac{\partial \overline{w'w'w'}}{\partial z}$; plus: $-\frac{\partial \overline{u'w'w'}}{\partial x}$)

4. SUMMARY AND DISCUSSION

A number of features in the velocity variance budgets are shared by three studies. Edge effects are reflected as sudden and sharp variations of the budget terms in streamwise and vertical velocity variances. It is identified that the shear production term, the major source of streamwsie velocity variance, starts to increase earlier on the back of the edge than the pressure redistribution term, the major sink of streamwise velocity variance but primary source of vertical velocity variance. This feature agrees with the finding of Morse et al. (2002) and may explain the different adjusting rates between velocity components.

Acknowledgements

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