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THE SCALAR BUDGET OF TURBULENCE FLOW ACROSS A FOREST EDGE: USING A LARGE EDDY SIMULATION (LES)

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1. INTRODUCTION

In recent years the eddy covariance technique has been a popular method in micrometeorological flux measurement. However, some existing problems have appeared to undermine this technique, for example those resulting from horizontal advection due to inadequate fetch and the effect of non-zero vertical velocity (Lee, 1998). In this study an attempt has been made to investigate the effect of advection on scalar transfer across a forest edge by using large eddy simulation (LES). The results from this study, hopefully, will provide a guideline for fetch requirements in flux measurement by the eddy covariance technique.

2. MODEL

The large eddy simulation used in this study is adapted from Moeng (1984), as modified by Patton (1997) by adding a forest canopy as the lowest part of the domain. The forest canopy is represented by specifying at each grid node an area density of drag elements (leaves, branches etc.). Thus, the effect of the canopy is introduced into the model by adding a drag force term to the Navier-Stokes equations. Further details about the model can be found in Patton (1997).

In order to form a forest edge, the computational domain is equally split into two parts along the streamwise direction, with one half representing a forest canopy and the other a meadow. A regular pattern alternating between forest and meadow is thus repeated each domain length because of the periodic boundary conditions imposed in the streamwise and lateral directions. The canopy covers 5 grid nodes vertically. With *h*=7.5 m as canopy height, the computational domain size is 38.4 *h* in the streamwise direction (*x*), 19.2 *h* in the spanwise direction (*y*) and 6 *h* in the vertical direction (*z*), respectively. At the domain top a frictionless and rigid boundary condition are imposed. At lower boundary a no-slip condition is applied and thus all components of velocity become zero there. In this simulation the leaf area index (LAI) is set to 2 and the volume averaged streamwise speed is 2.3 ms^{-1}.

The governing equation for the scalar, after a vertical integration from ground to *h*, can be written as (Paw U et al. 2001)

$$\int_0^h \frac{\partial \overline{C}}{\partial t}dz + \int_0^h \overline{u}\frac{\partial \overline{C}}{\partial x}dz + \int_0^h \overline{w}\frac{\partial \overline{C}}{\partial z}dz + \int_0^h \frac{\partial \overline{(u'C')}}{\partial x}dz + \left(\overline{w'C'}\right)_h + \int_0^h \frac{\partial \overline{\tau_{Cx}}}{\partial x}dz + \left(\overline{\tau_{Cz}}\right)_h = \int_0^h s\,dz .$$

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In the above equation, an over-bar indicates a time and *y*-averaged quantity while a prime denotes a departure from the average. *C* is the concentration of scalar. The '*u*' and '*w*' are the components of resolved scale velocity, while 'τ' is the sub-grid scale flux density. The '*s*' to the right hand side of the equation represents the scalar source. The scalar is only released in the canopy area and the source term is horizontally homogeneous but vertically depends on the leaf area density. The model of scalar source can be found in Shaw et al. (1992).

3. RESULTS

In this paper we are more interested in the scalar budget at the leading edge than the trailing one and therefore will confine our discussion to this region. The distance and height in all diagrams will be presented in normalized form. Position zero indicates the edge and ground level and a positive value means downwind of the edge and the height above ground.

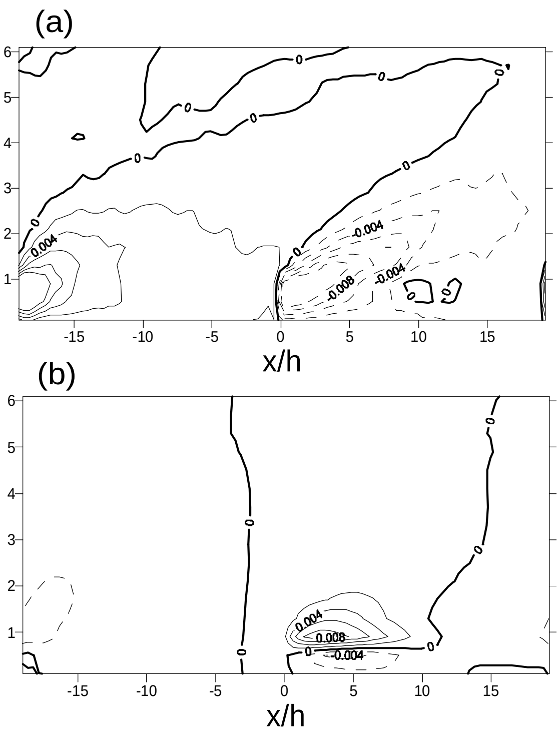

Figure 1: Contour plots of advection terms in the scalar equation with horizontal advection, $-\overline{u}\frac{\partial \overline{C}}{\partial x}$, in (a) and vertical advection, $-\overline{w}\frac{\partial \overline{C}}{\partial z}$, in (b). Solid lines denote positive values and dashed lines denote negative values.

Strong horizontal and vertical advection of scalar by the mean flow can be seen at the forest edge and in the transition region (Figure 1). The horizontal advection extends from the edge to about 10 *h* downwind within canopy layer, and beyond the location above tree height. The maximum advection appears between the edge and 5 *h* at the level of maximum leaf area density. The contour lines representing the region of the advection tilt upwards, expressing the growth of flow adjusting layer. The large gradient of scalar concentration between the upstream flow and the adjusting flow causes relatively strong horizontal advection at the interface.

Figure 1(b) shows the vertical advection of scalar, triggered by the mean upward vertical motion caused by the flow distortion at the leading edge. The region of vertical advection extends from 3.5 *h* upstream of the edge to about 8 *h* downstream and in vertical depth from ground to about 2-canopy height. It is interesting that the vertical advection is positive above 0.7 *h* but negative below it. The explanation lies in the setup of scalar source, which peaks at 0.7 *h* corresponding to the level of maximum area density of drag elements.

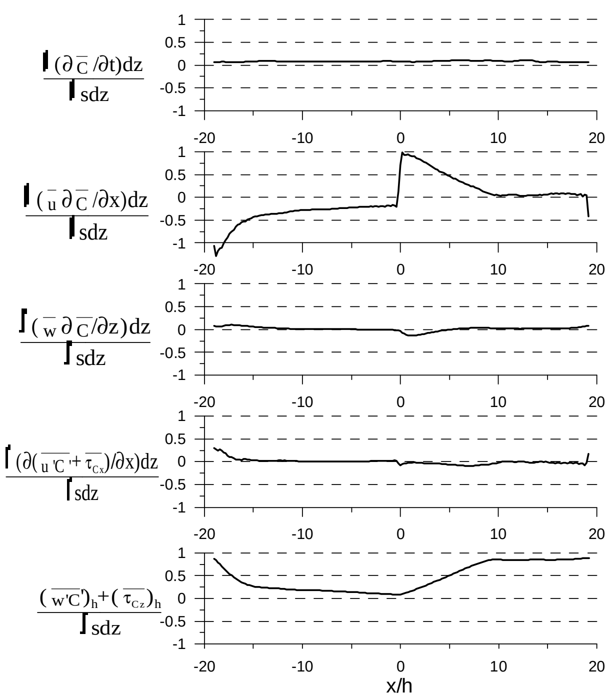

Figure 2: The ratios of the integrated budget terms to the source term. All terms are integrated from ground to canopy height.

Figure 2 shows the ratios of the vertical integration of each term to the source term. Within all of the vertically integrated budget terms, the horizontal turbulence transfer and the vertical advection by mean flow are relatively insignificant, except that vertical advection accounts for about 10% of the source in the region from the edge to about 3 *h* downwind. The storage within the canopy (vertical integration of time derivative term) is relatively constant along the flow direction and about 10% of the source term in this particular case. Immediately at the back of the forest edge the horizontal advection is very large and almost balances out the scalar source, while the upward flux (the resolved scale plus the sub-grid scale) at the canopy top is negligible. The former is ten times larger than the latter. As the flow adjusts to the new roughness surface, the ratio of integrated horizontal advection to source decreases from about 100% at the edge to a few percent at 10 *h*, while the ratio of upward scalar flux at tree height to the source increases from about 10% at the edge to 90% at 10 *h*.

4. CONCLUSION

The outputs from our LES demonstrate that strong horizontal and vertical advection of scalar make important contribution to the scalar budget at a forest transition, where turbulence flux contribution is weak because the turbulent motion from upstream is suppressed by the forest stand. The vertical eddy flux term reaches an equilibrium value at about 10 canopy heights downwind from edge, where advection terms become negligible. A fetch factor of at least 10, in this case, is needed if solely relying on eddy flux measurements.

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