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MIXING IN OPEN CANOPIES

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1. Introduction

In open canopies, the subcanopy flux can account for a significant fraction of the total flux from the canopy. In more open canopies, mixing within the canopy is strongly influenced by stability due to formation of surface inversions at night and patchy ground-surface heating during the day. This stability dependence has not been rigorously estimated from eddy-correlation data. The microscale heterogeneity of the subcanopy complicates the estimation of representative fluxes.

In addition, the surface fluxes from the ground floor may not establish equilibrium with the subcanopy air because of occasional turbulent events penetrating from above the canopy. Underestimated subcanopy turbulence in models can cause unrealistically large ground-surface temperatures, which strongly influence other land- surface processes in sparse canopies (Zeng et al. 2003). Many studies have examined airflow and turbulence within dense canopies noting the importance of sweeping events on the within canopy transport (Raupach et al., 1996, Zeng and Takahashi, 2000, Meyers and Paw, 1986). Less attention has been given to heat flux in sparse canopies where daytime subcanopy turbulence may be generated more by local buoyancy than downward transport of turbulence from above the canopy. The effect of within canopy stability on the turbulence needs to be considered properly in the subcanopy parameterization rather than assuming an exponential vertical profile of turbulent diffusivity extrapolated downward from above the canopy.

In this study, we construct a subcanopy formulation of the eddy diffusivity for within canopy mixing. The eddy diffusivity approach omits important physics such as transport counter to the local gradient by larger-scale sweeps (Wilson et al. 1998). However, in open canopies, the influence of within canopy stability appears to play a more important role.

2. Data

This study analyzes tower data collected at four levels on the main tower in old aspen site in BOREAS. Momentum fluxes were computed for 30-min records. The instrumentation at old aspen site is detailed in Blanken et al. (1997). We also analyze data collected in a ponderosa pine site in Central Oregon, USA during the summers of 2002 and 2003. At the mature pine site, turbulent fluxes were measured above the canopy and at two levels within the canopy, one in the crown space (10m)and one in the trunk space (3m). The flux at 3m was measured at the subcanopy tower separated from the main tower by 40m. Wind speed and air temperature were measured at 5 levels (3m, 6m, 10m, 20m, 30m) on the main tower. The air temperature was also measured on the subcanopy tower at 1m, 2m and 3m.

Table 1 Site description

Study sites	Average canopy height (m)	LAI
Old aspen	20.1	3.0
Pine	15.5	3.3

3. Mixing length in the subcanopy

The eddy diffusivity in the canopy can be expressed in terms of the product of a velocity scale, here the local height-dependent friction velocity, and a mixing length such that

$$K = l\, u_{*local} \qquad (1)$$

Applying Eq. 1 to the eddy diffusivity formulation of the momentum flux, the formulation of mixing length for momentum is given by

$$l_m = \frac{u_*}{du/dz} \qquad (2)$$

To examine the vertical profile of mixing length in the canopy, we computed the mixing length directly from

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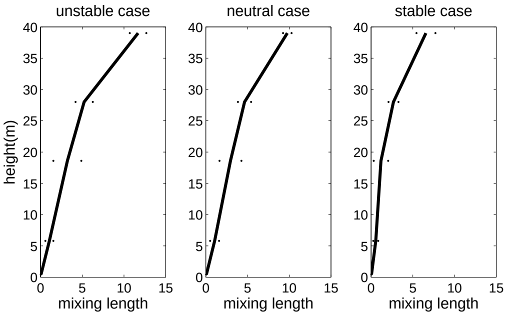

Figure 1: Height dependence of the mixing length e mated from vertical profiles at the old aspen site.

eddy-correlation measurements at the aspen site according to Eq. 2. At 39m where wind shear is not available, the mixing length was computed from Monin-Obukhov similarity theory. The resulting mixing length for momentum varies approximately linearly with height, but with a smaller slope within the canopy (Figure 1). The mixing length is much smaller in stable conditions compared to unstable conditions.

To formulate the height dependence of the mixing length, we recognize that height above the ground surface influences the within canopy mixing while the mixing length should approach Monin-Obukhov similarity theory in the surface layer above the canopy. For neutral conditions within the canopy, we propose the simple height dependence

$$l = \beta z \tag{3}$$

where β is related to the total LAI and z is the height above the ground surface. We require the mixing length in the canopy to approach Monin-Obukhov similarity as the LAI of the canopy vanishes. To also satisfy Monin-Obukhov similarity at the top of the roughness sublayer z_r, β can be formulated as

$$\beta = 0.4(z_r - d)/z_r \tag{4}$$

where d is displacement height and is the function of LAI. z_r is calculated following Raupach (1994).

4. Subcanopy turbulence

To examine the stability dependence of the mixing length in the subcanopy, we examined flux-gradient relationship using the two levels at the mature pine site, one in the crown space (10m) and the other in the trunk space (3m). Transition periods are eliminated by analyzing only daytime data between1000 and 1600h local and nocturnal data between 2100 and 0500h local time. Since the subcanopy tower at 3m is separated from main tower,

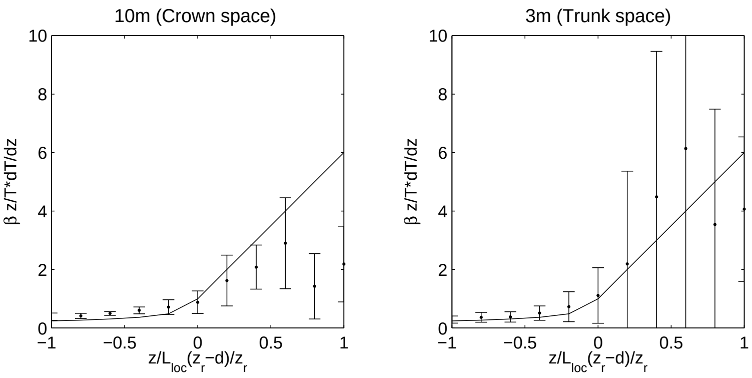

Figure 2: Nondimensional temperature gradient as a function of stability. Solid line corresponds to the stability function based on Monin-Obukhov similarity theory

we use only data where the horizontal temperature difference at 3m between the subcanopy and main towers is less than 0.5 K. Fig. 2 shows the non-dimensional temperature gradient in the subcanopy as a function of stability z/L scaled by the ratio of $(z_r - d)/z_r$. The ratio comes from the continuity of local stability below and above the canopy. The nondimensional temperature gradient is normalized by the value at neutral conditions. The nondimensional temperature gradient in the trunk space is related to the stability for unstable and near-neutral conditions in the subcanopy but varies erratically for stable conditions. These results indicate that local instability due to heat fluxes in the canopy strongly influences the transport with daytime heating of the ground surface. These results should not be interpreted as verification of Monin-Obukhov similarity. The strong height dependence of the heat flux in the canopy precludes formal application of Monin-Obukhov similarity theory. The erratic behavior in stable conditions may be due to separation between the subcanopy tower and the main tower since heterogeneity in the subcanopy is greater during stable conditions. However, the onset of drainage flow in the subcanopy also complicates the relationship between the fluxes and vertical gradients. The nondimensional temperature gradient at 10m depends on stability but less so than in the subcanopy trunk space.

5. Subcanopy structure

The vertical structure of the nocturnal flow at the mature pine site is sometimes includes cold air drainage in the subcanopy trunk space, capped by a strong inversion at about 10 m. The data were divided into strong inversion nights where temperature difference between 3m and 20m is larger than 5K and weak inversion nights where the temperature difference between 3m and 20m is

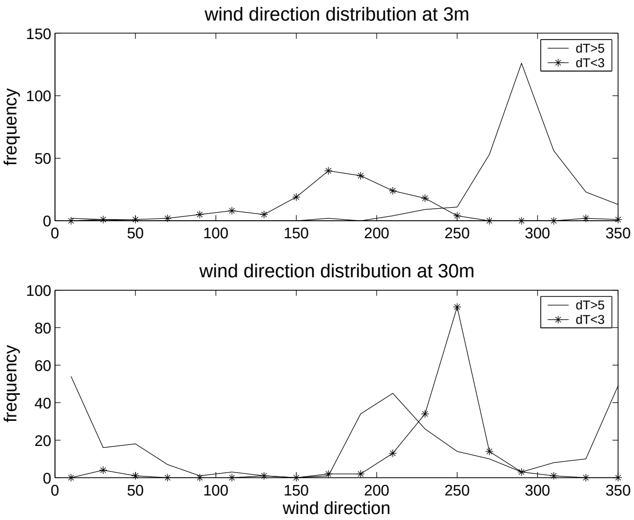

Figure 3: Frequency distribution of the wind direction at the mature pine site.

less than 3K. The frequency distributions of the nocturnal wind direction for the two cases (Figure 3) indicates westerly flow with strong inversions, corresponding to cold air drainage down the eastward descending slope, just west of the tower site. The tower is located over flat ground near the bottom of this slope. For weak stratification, the frequency distribution of the 3-m wind direction indicates a preference for more southerly flow, more typical of the regional flow above the canopy.

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