2.1 TURBULENCE STATISTICS AND SPECTRA IN AND ABOVE A HARDWOOD FOREST CANOPY FOR LAGRANGIAN STOCHASTIC MODEL APPLICATIONS.

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1. INTRODUCTION

To drive a Lagrangian stochastic dispersion model in and over a forest, vertical profiles of turbulence statistics characteristic of a forest environment are needed. In view of this requirement, turbulence measurements were collected in and over a mixed hardwood forest at the University of Michigan Biological Station (UMBS~Flux) in the summer 2000. Vertical velocity and temperature fluctuations were measured at four levels in the canopy, using 1-D sonics and fine wire thermocouples. Three dimensional velocity and temperature fluctuations were available from 3-D sonics at canopy height (H=21.4m) and at 1.6 and 2.1H on the UMBS~flux tower. Six additional thermocouples were distributed over the canopy layer depth. Vertical profiles of buoyancy flux, mean horizontal velocity, Reynolds stress, standard deviation and skewness of velocity components were calculated. Velocity spectra were computed to explore the potential of estimating the viscous dissipation rate, although preliminary results suggest that the high frequency range of the spectra do not always exhibit the roll-off predicted by Kolmogorov theory. Turbulence statistics profiles and spectra were analyzed and compared in five atmospheric stability classes determined above the canopy (stable, moderately stable, near neutral, moderately unstable, very unstable). The differences among them and their relation to the turbulence motion throughout the canopy is discussed here. The analysis of these measurements will be used to determine a multi-layer parameterization framework of turbulence statistics for implementation in an LSD model for forest canopies.

The University of Michigan Biological Station site (45°35' N, 84°42' W) lies in the north of Michigan's lower peninsula in a northern hardwood forest dominated by only five tree species (Schmid *et al*., 2002). The maximum VAI for 1999 at UMBS was 3.9 ± 0.1 m.

2. TURBULENCE STATISTICS

To obtain a preliminary view of the general structure of turbulence at the UMBS~flux site, stability profiles, normalized wind velocity and Reynolds stress were calculated above the canopy.

Figure 1 shows the profiles for the normalized mean wind U/u* plotted against $(z-d)/z_0$, in different stability conditions. The curves for different stability classes generally agree with the expected trend in the surface layer with slight deviations detected closer to the canopy. These are likely due to the influence of individual roughness element in the vegetation below.

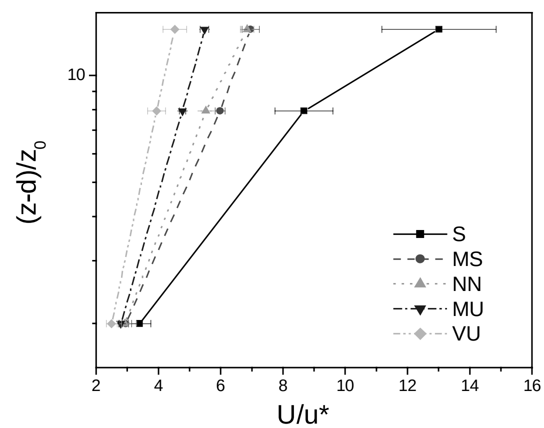

Figure 1: Vertical profile for the normalized mean wind U/u*, plotted against $(z-d)/z_0$, in different stability conditions. The symbol S stands for stable; MS for moderately stable; NN for near neutral; MU for moderately unstable; and VU for very unstable.

The properties of turbulence statistics in the flow above and within the canopy generally agree with the findings in the literature for similar studies conducted in near neutral cases (i.e. in Raupach et al., 1996). Figure 2 shows vertical profiles of the w-velocity skewness above and within the canopy. Above the forest, at 2.1H and 1.6H the w-skewness is very close to zero (or slightly positive), as expected in surface layer scaling (Kaimal and Finnigan, 1994). These values do not change significantly in different stability conditions. Inside the canopy the w-skewness becomes negative, reaching values of about –1.6 in the lower third of the canopy. This finding supports the notion that vertical motion within the canopy is dominated by downward-moving structures shed from the canopy top. The w-skewness values near the forest floor in the different stability cases suggest that turbulent incursions are more frequent and effective in near neutral above-canopy flow, when the w-skewness has the largest negative value, and they are suppressed in stable cases characterized by the smallest magnitude of w-skewness.

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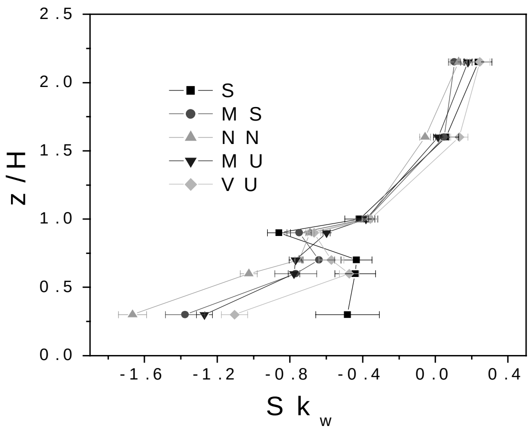

Figure 2: Vertical profile of the normalized skewness for the w-velocity component ($Sk_w = \overline{w'^3} / \sigma_w^{\ 3}$) calculated inside and above the canopy in different stability conditions. The symbols used are the same as in Fig.1.

3. COMPOSITE POWER SPECTRA

Figure 3 shows composite power spectra for the w-component at 2.1H (a) and 0.3H (b). The w-spectra at 2.1H are very similar to the distributions commonly found in the atmospheric surface layer (Kaimal and Finnigan, 1994). There, spectra are characterized by a single broad peak that shifts towards lower frequencies in very unstable conditions and to higher frequencies in stable conditions. In the latter case, turbulence structures are likely to be reduced in length and time dimensions (assuming Taylor's hypothesis applies). Spectra generally decrease with an only slightly smaller slope than predicted by Kolmogorov theory, which confirms that this level complies to surface layer scaling fairly well. Panel (b) of Figure 3 shows composite power spectra for the w-component at 0.3H. In contrast to the spectra above the canopy, the peaks in the distribution occur at the same normalized frequency at all above-canopy stabilities ($f_{max} \approx 0.7$). At increasing frequencies, the distribution decreases with a variable slope that is generally greater in magnitude than predicted by Kolmogorov theory. The spectral peaks inside the canopy are generally higher and more narrow than above the canopy, which suggests that turbulent eddies exhibit a smaller range of scales, and that the in-canopy spectra are dominated by large eddies shed at the canopy top. This finding agrees with the structure implied by the vertical profiles of the w-skewness, discussed above (Fig.2).

The consequences of accounting for this pronounced negative velocity skewness in Lagrangian diffusion models inside a forest canopy will be explored in other work.

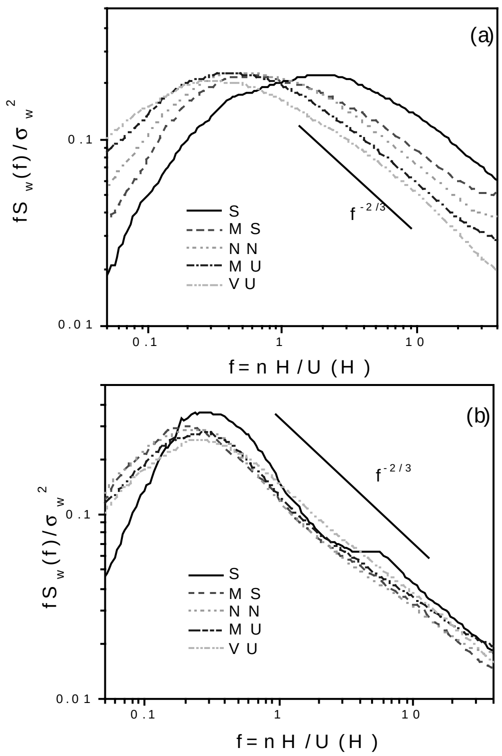

Figure 3: Normalized Power spectra for the w vertical component calculated at 2.1H (panel a) and inside the canopy at 0.3H (panel b). Different lines correspond to different stability conditions. The symbols used are the same as in Fig. 1.

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