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Interactive Comment

Interactive comment on "Observations of the scale-dependent turbulence and evaluation of the flux-gradient relationship for sensible heat for a closed Douglas-Fir canopy in very weak wind conditions" *by* D. Vickers and C. Thomas

D. Vickers and C. Thomas

vickers@coas.oregonstate.edu

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C. Thomas and D. Vickers, Additional responses, 17-Jul-2014

- 'The peak at very small timescales observed in the subcanopy" and related comment on 'In the first line of p.11937, sentence beginning with "it is also possible…": We would like to elaborate on our earlier comment as to why we think that this statement is important and our explanation physically meaningful.

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As evidenced in the spectra in Fig 2, central column, the heat fluxes at 16m and 4m are opposite in direction, but the magnitude of the 4m heat flux is only $\approx$ 15 to 25 % of that further aloft. Since both levels are located within the clear bole space of the sub-canopy and thus not separated by dense foliage restricting vertical (or horizontal for that matter) motions, it is conceivable that the heat flux contribution for the time scales dominating the 16m-flux (around 15s) cancel out near the ground at 4m as colder air is moved upward and mixes with the relatively cold, but still warmer air moving downward from the 16 m level. One would thus expect this canceling effect to create a gap in the spectra at time scales around 15s, as evidenced in Fig 2, bottom panel. Thus, the spectral gap must not be interpreted as evidence that motions on these scales don't exist or contribute to the heat flux. We argue that the double peaks are the result of the canceling contribution of opposing fluxes creating a gap in an otherwise continuous spectral peak, and thus must not be interpreted as evidence for physical processes generating motions with two distinctly different time scales of 1 and 200 s. The spectral minimum visible for the sub-canopy variance of the vertical velocity coincides with the time scales around 15 s, and its existence tallies with our interpretation since the mixing of air and cancelation of opposing fluxes near the ground would lead to suppressed vertical motions due to reduced buoyancy.

- 'Somewhat similar time scales of the turbulence maximum between different levels': We would like to add to our comment that the logarithmic scaling of the x-axis may be somewhat misleading. Comparing the location of the spectral peaks for, e.g., the vertical velocity variance across levels, one yields that the ratio of sub-canopy to above-canopy time scales exceeds two, while the ratio of sub-canopy (4m) to upper-boundary of the clear bole space (16m) equals unity for the nighttime, and also exceeds two for the daytime data. We agree with the reviewer's interpretation that this can be explained by the very closed, dense canopy. As evidenced by the direction and magnitude of the heat fluxes, the flow and trans-

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port at the 38 and 16 m levels communicate actively during the day indicating a coupled state, while the 4m level is buoyantly decoupled. At night, the 16 and 4 m levels are closely coupled, while the significant above-canopy stratification decouples observations further aloft at 38m. In addition to a shift toward increased peak time scale with decreasing proximity to the ground, we also call attention to the much broader spectral peaks for sub-canopy fluxes and vertical turbulence intensity compared to the more narrowly defined above-canopy peaks. The former indicate a variety of generating mechanisms, while the latter point to buoyancy as the single most important mechanism driving the above-canopy turbulence given the weak flow and resulting shear.

- ‘High turbulence intensities observed at the canopy level largely exceeding unity’: While we are not aware of similar observations reported in the literature, the suppression of horizontal over vertical motions can easily be explained when recalling the physical canopy architecture of the Douglas-fir trees: in the horizontal direction, the overlapping branches including their needles form an large, uniform ‘face’ and flow resistance when averaged over spatial scales exceeding that of a single tree. In the vertical direction, gaps in between individual trees that are visible from the top of the tower created narrow ‘canyons’ or ‘passages’ that do not impede the vertical flow. The combined effect of the differences in canopy architecture leads to a greater suppression of horizontal in comparison to vertical motions, thus relatively enhancing the velocity aspect ratio shown in Fig. 4. This ratio is largest for the time scales around 15s, which dominate the daytime heat fluxes and lead to a communication of air and coupled transport between the 16 and 38 m levels.

- ‘Large C_H values above the canopy compared to sub-canopy values, which agree well with values found in the literature, and effects of the roughness sublayer’: We would like to add that all three observational levels are located within the roughness sublayer, as it can extend from the surface ground to 3 to 5 times the

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14, C5051–C5054, 2014

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canopy height (Garratt, 1980; Raupach and Thom, 1981; Thomas et al., 2006). We would like to remind the reader that the 16m observational level does not correspond to the height of the upper, but lower boundary of the canopy. The velocity aspect ratio exceeding unity at 16m can therefore not be an indicator of the very intense turbulence above the canopy, but can rather be interpreted as the relatively stronger suppression of horizontal in comparison to vertical motions by the canopy architecture as detailed above.

Cited literature

1. Garratt JR. Surface influence upon vertical profiles in the atmospheric near-surface layer. Quart J Roy Meteorol Soc. 1980;106:803-819. doi:10.1002/qj.49710645011.

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3. Thomas C, Mayer J-C, Meixner FX, Foken T. Analysis of low-frequency turbulence above tall vegetation using a Doppler sodar. Boundary-Layer Meteorol. 2006;119:563-587. doi:10.1007/s10546-005-9038-0.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 11929, 2014.