10.8 **AN INVESTIGATION OF ADVECTION AND GULLY FLOWS IN COMPLEX FORESTED TERRAIN**

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1. INTRODUCTION

Measurements of net ecosystem exchange (NEE) of carbon, as well as the exchange of water and heat, are routinely made using the eddy-covariance technique at sites around the world. Recent research has questioned how to interpret these measurements, particularly over tall vegetation in areas of complex terrain. Evidence has been presented (e.g. Lee, 1998; Baldocchi *et al*., 2000) of underestimates of nighttime fluxes, likely due to horizontal and vertical advection. Lee (1998), assuming that vertical advection was dominant, proposed a correction term for vertical advection and indicated that local nocturnal thermally-driven drainage flow is likely the strongest driver of this advection. This paper examines mean horizontal and vertical flow above the forest canopy and thermally-driven gully flows below canopy at Morgan-Monroe State Forest (MMSF).

The MMSF AmeriFlux site, located in South Central Indiana (39° 19' N 86° 25' W), is situated in a mixed deciduous forest in ridge-ravine topography. Eddy covariance measurements are made at two heights (46 m and 34 m), from a tower erected on a ridge extending from NW to SE (Schmid *et al*., 2000). In the summer of 2001, a small (8 m) mast was installed for the purpose of examining flow in a gully below the forest canopy. This gully mast is located ~350 m to the SW of the main MMSF tower, in a gully which extends up towards the main tower. At the site of the gully tower, the gully is ~20-25m deep and is aligned with an azimuth of ~55°. The gully tower was instrumented with: a 2-D sonic anemometer at 1 m; a pair of 3-D sonic anemometers at 4 m and 7 m.; and five fine-wire thermocouples at heights between 1 m and 7 m.

2. MEAN VERTICAL WINDS ABOVE CANOPY

It is often assumed that mean flows follow the local topography. In traditional eddy covariance measurements, this assumption led to the practice of rotating wind vectors to a coordinate system in which the mean vertical velocity, over an averaging period of 15 minutes to 1 hour, is zero. However, if non-zero mean velocities normal to the terrain (W_r) are occurring over this averaging period as a result of flow divergence or convergence, this assumption may not be valid. It may then be more appropriate to rotate all wind vectors to a coordinate system in which the long-term mean of W_r is zero.

Frequency distributions of the mean vertical velocities (W_r) (Figure 1) show a tendency towards negative vertical velocities (downward) at night relative to the day. This tendency is stronger during the period of leaf-on and during the spring and fall transitional periods than during the period of leaf-off. Additional frequency distributions, not shown here, indicate that this tendency to downwards motion is stronger later in the night. Finally, this trend is stronger at 46 m than at 34 m.

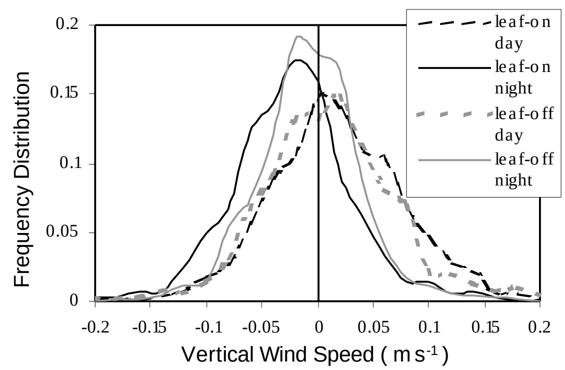

Figure 1: Frequency distribution of W_r at 34 m (1999). Leaf-on = day of year 125-280. Leaf-off = day 1-78, 329-365. Night and day include all hours from 1 hour past sunset/rise to 1 hour before sunrise/set.

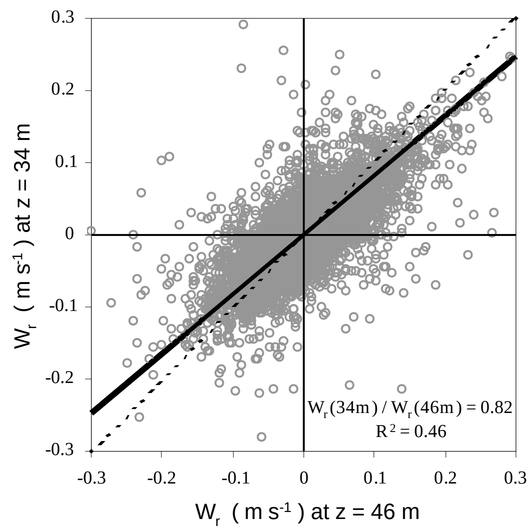

Figure 2: Comparison of the mean vertical velocity (W_r) at 46 m and 34 m. The solid line indicates a principal axis linear regression (slope = 0.82). The dashed line indicates a slope of 1:1. (data from 1999)

The vertical wind speeds are generally lower at 34 m than at 46 m (Figure 2). However, the slope of a regression line of the velocities at the two heights (0.82)

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is larger than the ratio of the two heights (0.74) indicating that the vertical motions may be driven by a horizontal divergence/convergence, which weakens with height.

Relationships with net radiative loss, temperature profiles and stability are generally weak, but indicate that downward vertical motion is most pronounced on nights with strong net radiative loss and strong temperature inversions. This is consistent with vertical convergence and horizontal divergence arising from thermally-driven nocturnal drainage flows.

3. BELOW CANOPY GULLY FLOWS

Wind in the gully was observed to flow along the axis of the gully, with few exceptions. Most commonly, the direction of flow (up- or down-gully) was strongly correlated to the component of the wind vector above canopy, in the direction approximately parallel to the orientation of the gully. However, there were several periods when the gully flow appeared to be decoupled from the flow above the canopy; these flow patterns occurred during periods of strong insolation by day and strong net radiative loss at night (Figure 3).

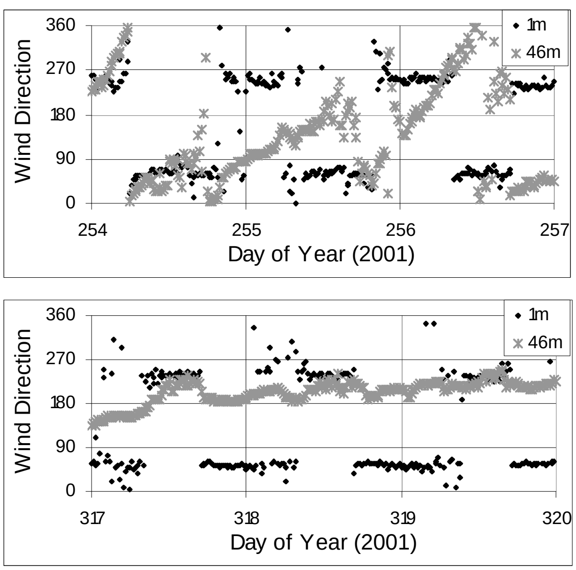

Figure 3: Wind direction during two periods at 1 m height in the below canopy gully and at 46 m above the forest canopy. Both periods were dominated by clear skies with large positive net radiation by day and strong radiative cooling at night. The direction of flow below canopy showed little relationship to the direction of flow above canopy. Direction of flow was consistent at each of the 3 measurement heights below canopy. Days 254-257 (mid-September): VAI≅4.5 (vegetation area index). Days 317-320 (mid-November): VAI≅1. In the gully: 53° = down-valley flow; 233° = up-valley flow.

During days 254-257, flow was consistently up-valley at night and down-valley in the day. While contrary to the typical picture of thermally-driven flow, this was consistent with the temperature profiles that were observed. Below the canopy, a temperature inversion occurred during the day and lapse conditions at night, resulting from daytime heating and nighttime cooling in the dense canopy layer.

By contrast, during days 317-320, temperature profiles showed nocturnal inversions and daytime lapse conditions above, within and below the canopy during leaf-off. Flow was consistently up-valley during the day and down-valley at night.

In both periods, there was a significant correlation between the along-valley wind velocity in the gully and vertical velocity above canopy. During leaf-off, nocturnal down-valley winds (away from the tower) were well correlated with downward net vertical velocities above canopy, consistent with the simple flow pattern with uniform horizontal divergence and vertical convergence suggested by Lee (1998). During leaf-on, nocturnal up-valley (towards the tower) winds, indicating horizontal flow convergence, were well correlated with vertical convergence; this implies a stronger horizontal flow divergence above and/or within the forest canopy.

4. IMPLICATIONS

This research indicates that the three-dimensional flow structure at MMSF is more complex than in non-forested gully flow. Furthermore, there are indications that the flow patterns change over the seasons, with different canopy structure. This lends further support to the suggestion that the inclusion of a simple vertical advection/divergence term in calculations of NEE, based on above-canopy measurements, is not generally applicable (Finnigan, 1999). These results warrant further investigation into the flow patterns at MMSF, including horizontal flow divergence/convergence at heights above or within the canopy.

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