Evaluating Horizontal and Vertical Fluxes in the Hubbard Brook Experimental Forest

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1. Motivation

- How forests' use of water, energy, and carbon dioxide changes in a rapidly changing climate has profound implications for the global climate.
- To advance knowledge of how a forest uses these resources, it is critical to understand wind patterns above and below the forest canopy.
- Turbulence can create a coupled wind regime that moves resources through the canopy, though horizontal flows below canopy can also produce significant fluxes of resources.
- This research evaluates the energy budget and quantifies the horizontal fluxes of carbon dioxide and water vapor.

2. Introduction

- The Hubbard Brook Experimental Forest (HBEF) in North Woodstock, New Hampshire, USA on Abenaki land
- 35 km^2 or 8,700 acres
- Temperate mixed deciduous and conifer forest, with heterogeneous canopy
- 20-m canopy with sparse undergrowth

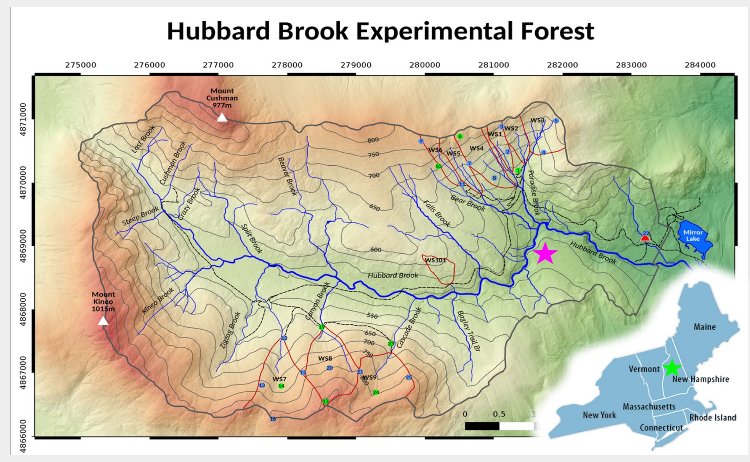

Figure 1. Map of the HBEF in NH. Eddy covariance tower located at pink star and HBEF located at green star on US regional map.

3. Methodology

- Above- and below-canopy measurements taken at the top of a 30-m eddy covariance tower and at 6 m AGL
- Instrumentation includes a 3-D sonic anemometer and LI-COR gas analyzer (H_2O, CO_2) and 10 Hz measurements were averaged into 30 min intervals
- Dataset spans 25 May - 16 June 2022 and 18 May - June 9 2023
- The friction velocity (u*) coupling metric[1,2] was employed:

$$u^* = \sqrt[4]{\overline{u'w'}^2 + \overline{v'w'}^2}$$

Figure 2. The above-canopy instrumentation on the eddy covariance tower in the HBEF.

- The energy budgets from 2022 and 2023 were evaluated with the decoupled flux correction method from Paul-Limoges et al. (2017) and Thomas et al. (2013) with below-canopy fluxes added to above-canopy measurements
- The energy budget refers to the accounting of solar energy after it is redistributed in the forest ecosystem via the components of R_{net} (Net Radiation), H (Sensible Heat Flux), LE (Latent Heat Flux), and G (Ground Heat Flux)

$$R_{net} = H + LE + G$$

4a. Results: Coupling Thresholds

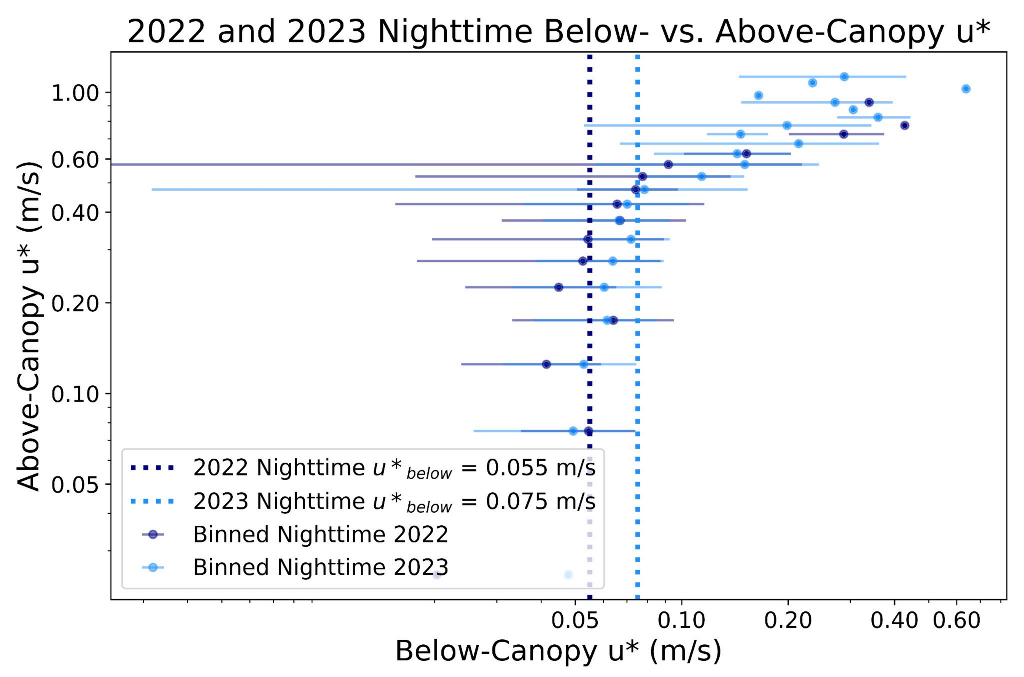

Figure 3. The nighttime friction velocity (u) for 2022 and 2023 using binned averages and standard deviation bars for above-canopy u*. The dashed lines indicate the nighttime u* thresholds for for both years, determined from the inflection points of the slopes. Note the logarithmic scale for both axes.*

- A lower u* threshold for 2022 (Fig. 3) means that less turbulence was required for the air masses to be considered coupled
- This threshold difference might be linked to a difference in canopy density between the years of the dataset

4b. Results: Energy Budget Closure

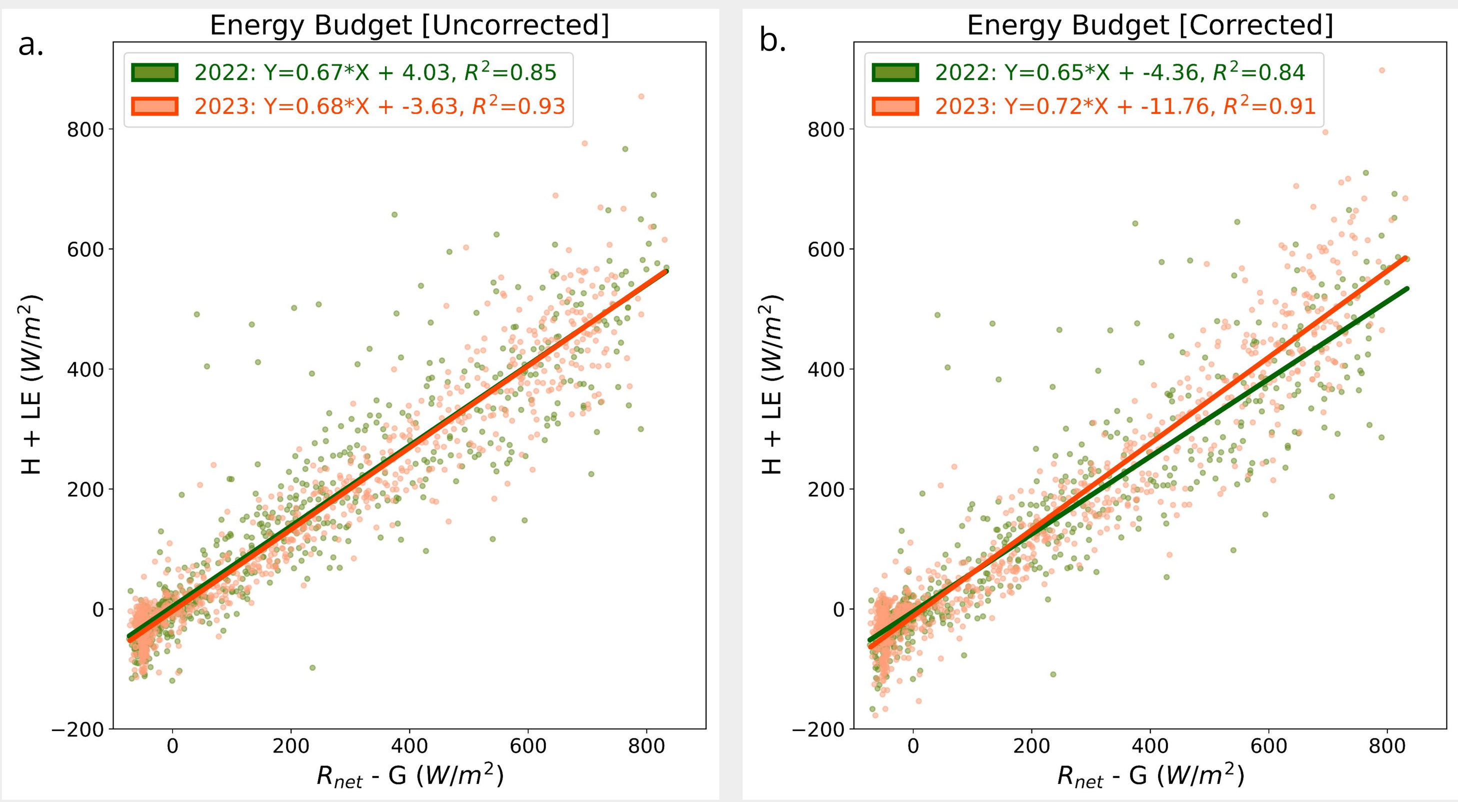

Figure 4. The energy budget for 2022 and 2023 based on a) the above-canopy measurements for latent and sensible heat fluxes (LE and H) and b) the decoupled flux correction, which adds the below-canopy LE and H to the above-canopy measurements.

- The 2022 portion of the dataset shows a higher budget closure of 67% for the uncorrected model (Fig. 4a) while the 2023 portion shows higher closure of 72% for the decoupling correction model (Fig. 4b)
- The 4% increase in budget closure in 2023 with the flux correction model accounts for ~6.8 W/m^2
- This suggests that 2022 was more coupled than 2023 and above-canopy measurements accurately detected below-canopy fluxes
- A decoupled correction model based on u* thresholds for 2023 (not shown) did not close the energy budget as effectively as the fully-corrected model
- The 2023 correction (Fig. 4b) supports the findings of Paul-Limoges et al. (2017) of frequent decoupling in the summer
- More data points will help to increase the confidence in these findings

4c. Results: Horizontal Advection

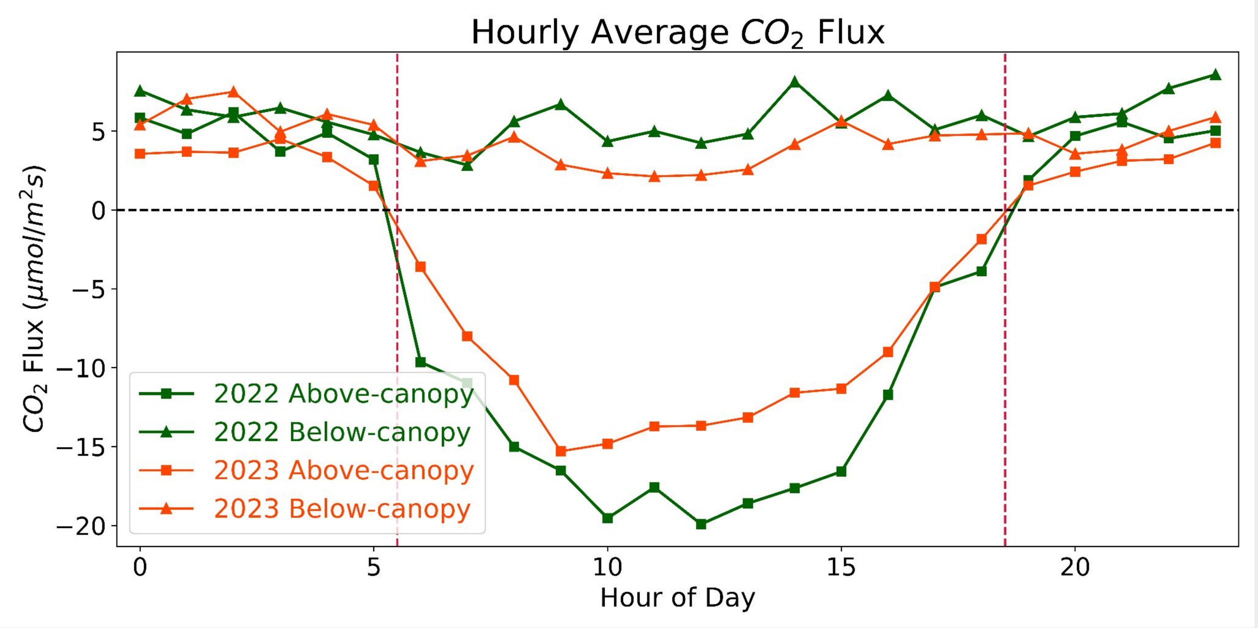

Figure 5. The average CO_2 flux by hour above- and below-canopy for 2022 and 2023. The red dashed lines indicate day and nighttime.

- During the overnight hours, differences in above- and below-canopy CO_2 flux (Fig. 5) are associated with CO_2 being lost via horizontal advection, and the flux difference is larger for 2023 (Table 1)

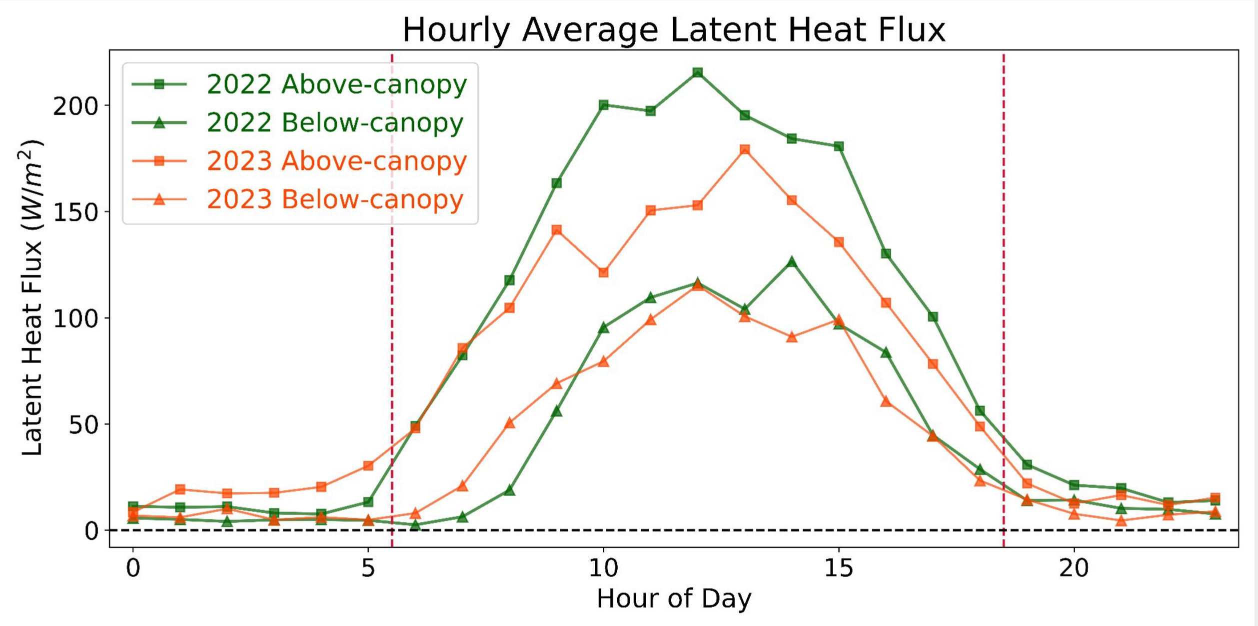

Figure 6. The average LE flux by hour above- and below-canopy for 2022 and 2023. The red dashed lines indicate day and nighttime.

- During the overnight hours, differences in above- and below-canopy LE flux (Fig. 6) are associated with water vapor being gained via horizontal advection, and the flux difference is larger for 2023 (Table 1)
- This implies that there was more horizontal advection and decoupling in 2023 than 2022 in the overnight hours
- Horizontal advection likely also occurs during the day, but it is more difficult to quantify since biological processes also contribute to the fluxes

	2022	2023
CO_2 Flux	-1.66 mol/m^2	-2.54 mol/m^2
LE Flux	0.055 mm/m^2	0.081 mm/m^2

Table 1. The integrated overnight (1900 - 0500 EST) flux differences for CO_2 and LE for 2022 and 2023, using above-canopy minus below-canopy.

5. Conclusions & Future Work

- 2022 was likely more frequently coupled than 2023 from a lower u* threshold, higher energy budget closure, and less overnight horizontal advection
- Overnight below-canopy horizontal fluxes export CO_2 and import H_2O via katabatic (mountain) flow
- Further investigation with more data is needed to examine seasonal and larger-scale temporal variability in wind and flux patterns

References & Acknowledgements

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[2]Thomas, C. K., Martin, J. G., Law, B. E., & Davis, K. (2013). Toward biologically meaningful net carbon exchange estimates for tall, dense canopies: Multi-level eddy covariance observations and canopy coupling regimes in a mature Douglas-fir forest in Oregon. *Agricultural and Forest Meteorology, 173,* 14-27.

Virtual poster:

Coupling in the HBEF:

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