Cross-Canopy Coupling in a New England Forested Mountain Valley

Alyssa Shih[1], Jacqueline Kiszka[2], Eric Kelsey[3]

Northeast Partnership for Atmospheric & Related Sciences REU

University of Illinois Urbana-Champaign[1], Pennsylvania State University[2], Plymouth State University[3]

NEPARS

HOBART AND WILLIAM SMITH COLLEGES

Plymouth State UNIVERSITY

NSF REU

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.
- Defining regimes of coupled and decoupled winds will help gain a better understanding of how resources are circulating and being used in a forest.

2. Site Description

- 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 high canopy with sparse undergrowth
- Mountain flows (Fig. 2) run from west to east along the valley axis[3].

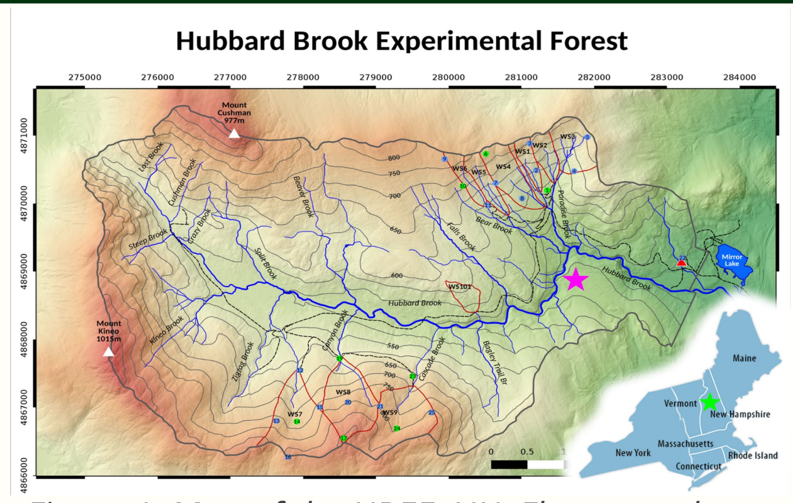

Figure 1. Map of the HBEF, NH. Flux tower located at pink star. HBEF located at green star.

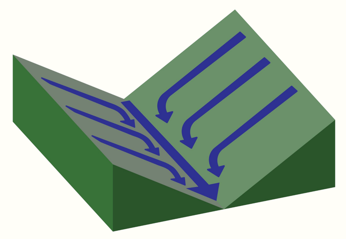

Figure 2. Idealized mountain flows.

3. Data and Methodology

Figure 3. The above-canopy instrumentation on the eddy covariance tower in the HBEF (30 m agl).

- Above- and below-canopy measurements taken at the top of a 30-m eddy covariance tower and at 6 m AGL respectively, located on a 5° slope
- 3-D sonic anemometer and LI-COR gas analyzer (H_2O, CO_2), temperature sensors every 3 m on tower
- 10 Hz data averaged into 30 min intervals
- Datasets span 25 May - 16 June 2022 and 18 May - 9 June 2023
- Synoptic-scale surface maps acquired from the NWS WPC's Surface Analysis Archive of United States (CONUS) Analyses
- Case studies of days with >70% of max daily incoming shortwave radiation, dubbed "clear sky days," were studied to determine common wind patterns.
- Several metrics of coupling from Jocher et al. (2017)[2], Thomas et al. (2013)[4], and Freundorfer et al. (2019)[1] were tested: friction velocity ($u*$) and the standard deviation of vertical velocity (σ_w).

$$u^* = \sqrt[4]{\overline{u'w'}^2 + \overline{v'w'}^2} \qquad \sigma_w = \sqrt{\frac{\sum (w')^2}{N}}$$

4a. Results: Impact of Synoptic-Scale Winds on Local Winds

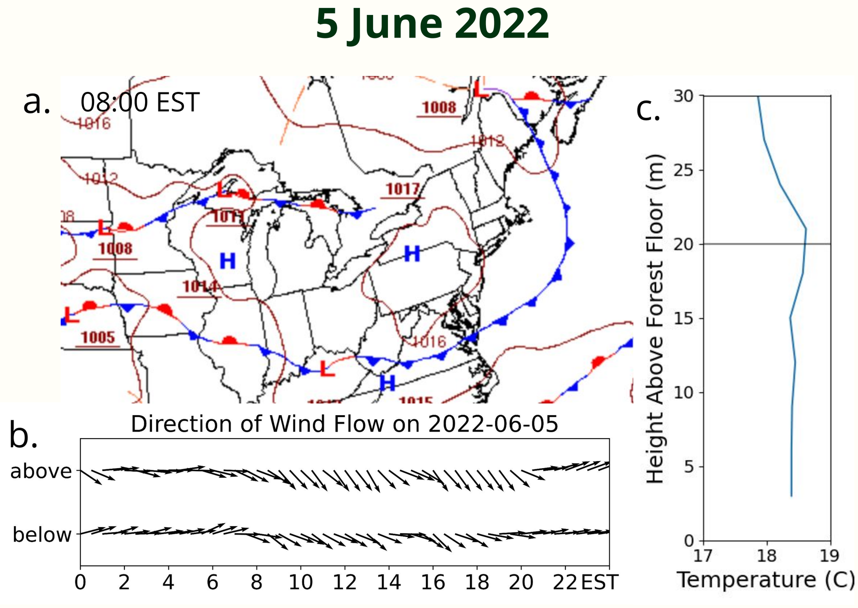

Figure 4. (a) Synoptic-scale map on 5 June 2022 at 08:00 EST. (b) Above- and below-canopy wind flow on 5 June 2023. (c) Temperature profile on 5 June 2022 at 15:00 EST.

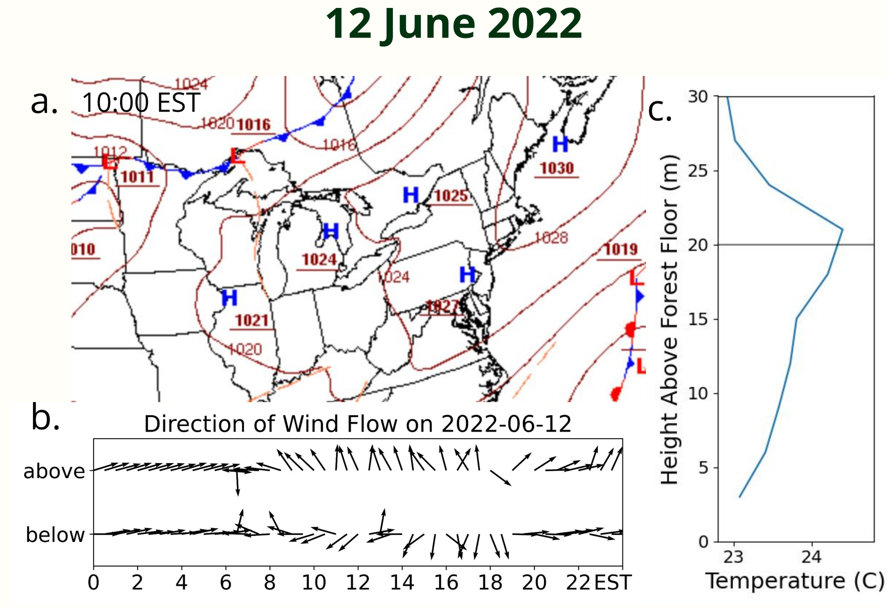

Figure 5. As in Fig. 4, (a) except for 12 June 2022 at 10:00 EST, (b) except for 12 June 2022, (c) except for 12 June 2022 at 13:00 EST.

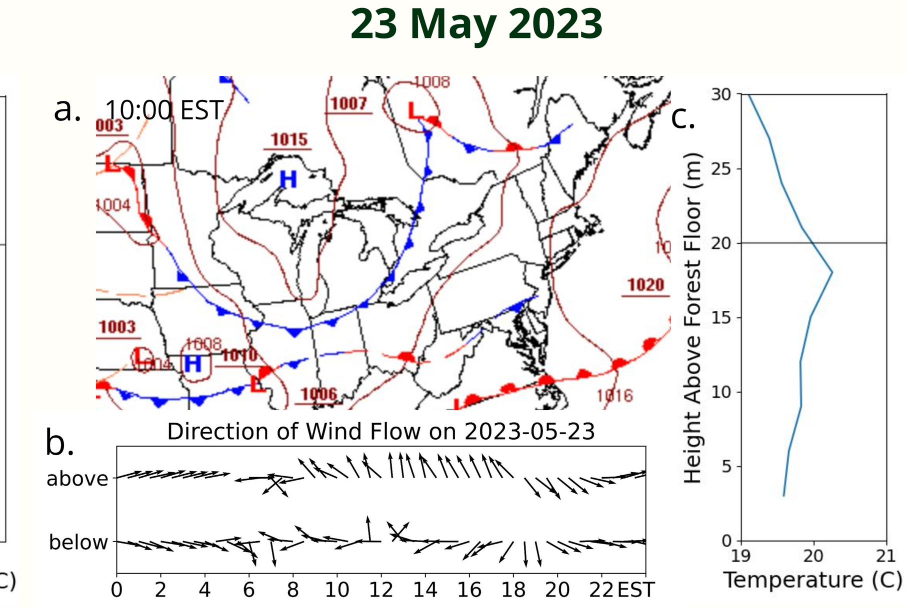

Figure 6. As in Fig. 4, (a) except for 23 May 2023 at 10:00 EST, (b) except for 23 May 2023, (c) except for 23 May 2023 at 15:30 EST.

- Nighttime above and below-canopy winds for all three case studies followed westerly mountain flows (Fig. 4b, 5b, 6b), a common pattern across both years.
- Daytime above-canopy winds were driven by synoptic-scale winds for all three case studies (Fig. 4, 5, 6), another pattern consistent across both years.
- Misaligned daytime winds (Fig. 5, 6) often corresponded to daily temperature inversions that formed around sunrise (Fig. 5c, 6c).

4b. Results: Cross-Canopy Coupling

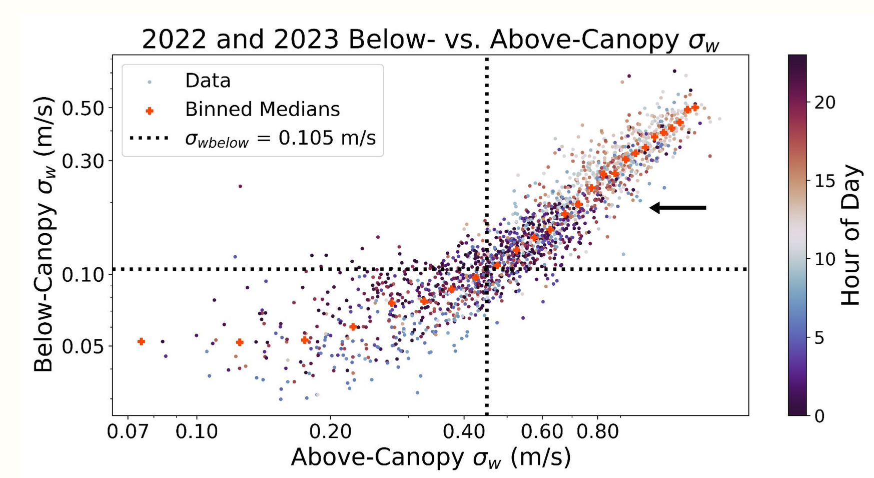

Figure 7. Above- vs. below-canopy σ_w, shaded by hour of day, after Jocher et al. (2017)[2]. Arrow indicates transition from mostly nighttime to daytime at $\sigma_{w\,below}$ = 0.19 m/s.

- Jocher et al. (2017)[2] determined coupled regimes in a boreal forest by observing where the binned averages of $\sigma_{w\,below}$ vs. $\sigma_{w\,above}$ suddenly changed from independent to linear.
- Applying this method to HBEF yielded $\sigma_{w\,below}$ > 0.105 m/s for coupled regimes (Fig. 7).
- At $\sigma_{w\,below}$ = 0.19 m/s, datapoints transitioned from nighttime to daytime and the slope becomes less steep.
- This transition has not been observed in other studies, but may be attributed to differing sources of turbulence.

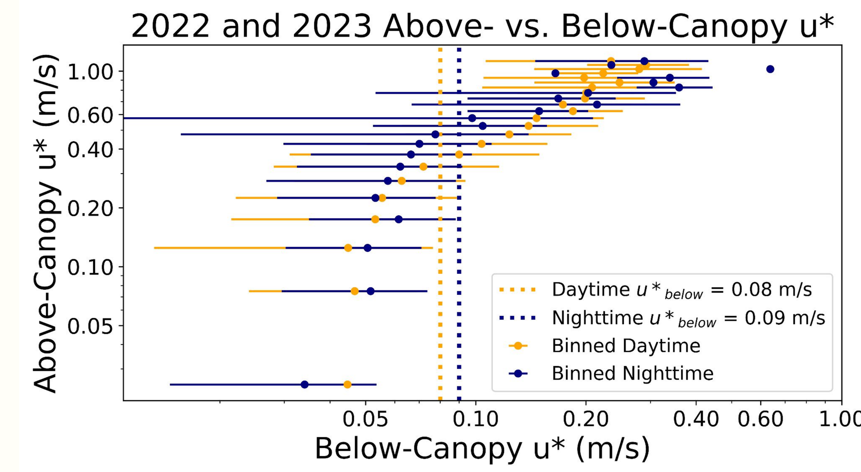

Figure 8. Above- vs. below-canopy u split by day and nighttime, after Thomas et al. (2013)[4].*

- Thomas et al. (2013)[4] split data by day and night to account for the differences in wind patterns, plotting $u*_{above}$ vs. $u*_{below}$ and finding transitions from independent to linear.
- In the HBEF, day and nighttime $u*_{below}$ cutoffs were found at 0.08 m/s and 0.09 m/s respectively (Fig. 8).
- The lower daytime $u*_{below}$ indicated that less turbulence was required for the air masses to be considered coupled.

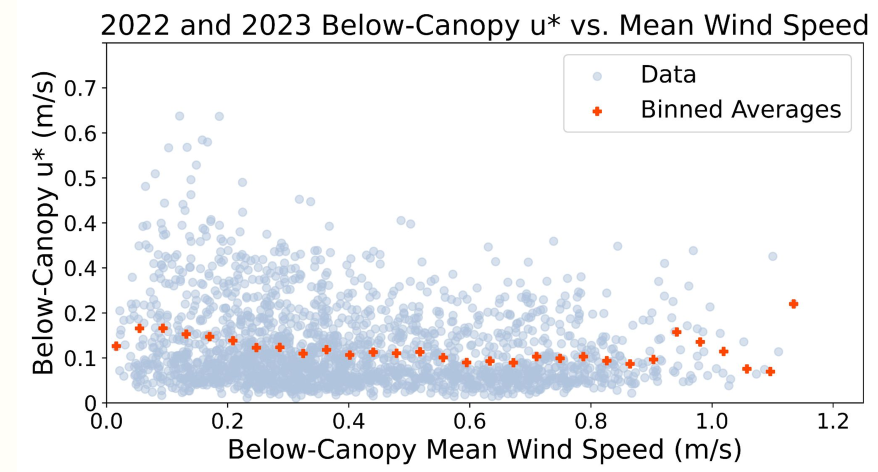

Figure 9. Below-canopy u vs. mean wind speed, after Freundorfer et al. (2019)[1], which did not yield a clear coupling cut off.*

- Freundorfer et al. (2019)[1] plotted $u*_{below}$ vs. $\bar{u}_{below}$ using a "hockey-stick method" to find the transition between independent and positively linear.
- This pattern was not found at HBEF (Fig. 9), likely due to the differences in forest structure and valley orography.
  - Freundorfer et al. (2019)[1] observed a Douglas-fir forest with a dense understory and valley slopes of up to 40°.

4c. Results: Coupling Metric Comparisons

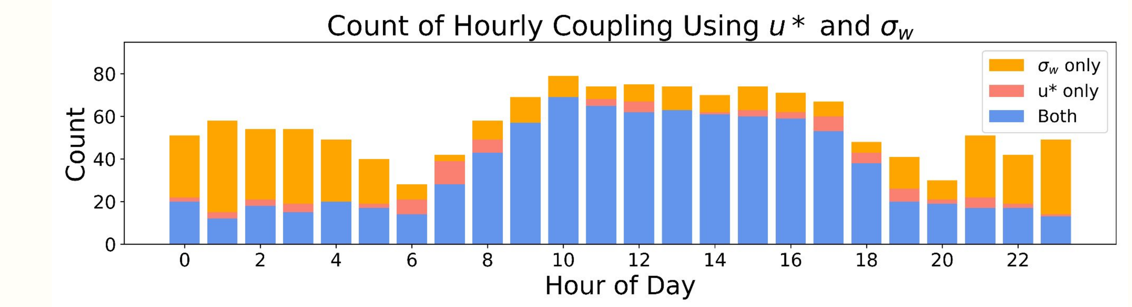

Figure 10. A histogram showing number of 30-min intervals when u and σ_w indicated coupling by hour of day.*

- Both the σ_w metric and $u*$ metric indicate that coupling occurs most frequently during the day (Fig. 10).
- The σ_w metric indicates significantly more coupling at night than the $u*$ metric (Fig. 10).
- The σ_w metric suggests brief decoupling during the transition periods of sunrise and sunset (Fig. 10).

5. Conclusions

- Above-canopy daytime winds were strongly influenced by the synoptic-scale wind patterns, whereas nighttime winds above and below the canopy often followed mountain flows.
- Both the σ_w metric and $u*$ metric agree that coupling occurs more frequently during the day.
- The σ_w coupling metric suggests a secondary coupling peak at night, with brief decoupling during sunrise and sunset.
- Differences in forest structure and valley orography between HBEF and other researched forests likely explain the differences between coupling threshold values.

References and Acknowledgements

Support for this project provided by the National Science Foundation REU program AGS-1757009. Data processing was done by Mark Green and Dan Evans.

[1]Freundorfer, A., Rehberg, I., Law, B. E., & Thomas, C. (2019). Forest wind regimes and their implications on cross-canopy coupling. *Agricultural and Forest Meteorology*, *279*, 107696.

[2]Jocher, G., De Simon, G., Hörnlund, T., Linder, S., Lundmark, T., Marshall, J., ... & Peichl, M. (2017). Apparent winter CO2 uptake by a boreal forest due to decoupling. *Agricultural and Forest Meteorology*, *232*, 23-34.

[3]Kelsey, E. P., Cann, M. D., Lupo, K. M., & Haddad, L. J. (2019). Synoptic to microscale processes affecting the evolution of a cold-air pool in a northern New England forested mountain valley. *Journal of Applied Meteorology and Climatology*, *58*(6), 1309-1324.

[4]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

Fluxes in the HBEF

Please direct questions or comments to ashih4@illinois.edu.