Supplementary Materials

Wolf S, Paul-Limoges E, Sayler D, Kirchner JW (2024) Dynamics of evapotranspiration from concurrent above- and below-canopy flux measurements in a montane Sierra Nevada forest. *Agricultural and Forest Meteorology*

⇒ Corresponding author: Sebastian Wolf, Department of Environmental Systems Science, Physics of Environmental Systems, ETH Zurich, Zurich, Switzerland (sewolf@ethz.ch)

Figure S1. Location of concurrent above- and below-canopy eddy covariance (EC) measurements at Sagehen Creek Field Station. Above-canopy (AC) measurements were conducted at 30 m height, and below-canopy (or subcanopy) measurements were conducted at the towers ‘Below Canopy #1’ (BC1) and ‘Below Canopy #2’ (BC2) at 2 m height. The background imagery was recorded on 7 June 2018 (Google Earth).

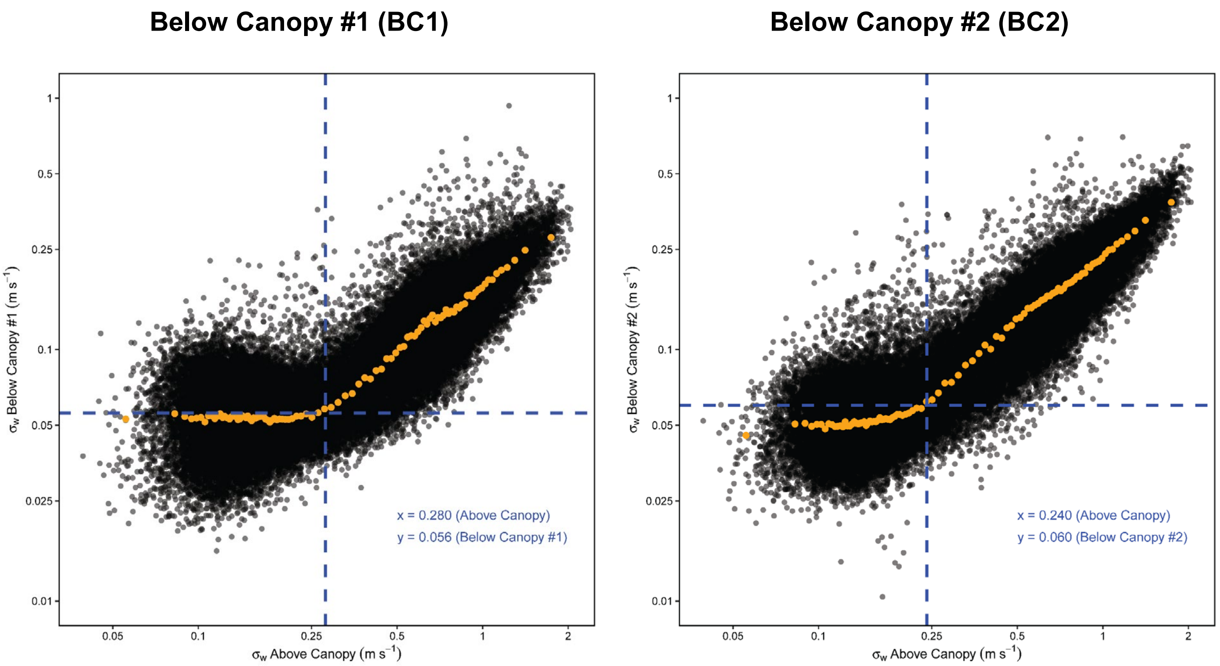

Figure S2. Decoupling assessment between above- and below-canopy exchange based on the standard deviation of vertical wind speed (σ_w). Grey points (which appear black when overlapped) are half-hourly averages and orange points are the median values of 100 quantile-based bins). Decoupling is assumed when the linear relationship between above- and below-canopy σ_w breaks down. The decoupling threshold is marked by the crossing point of the blue dashed lines and the coordinates of this threshold are denoted by the blue annotation. Please note that both axes are logarithmic.

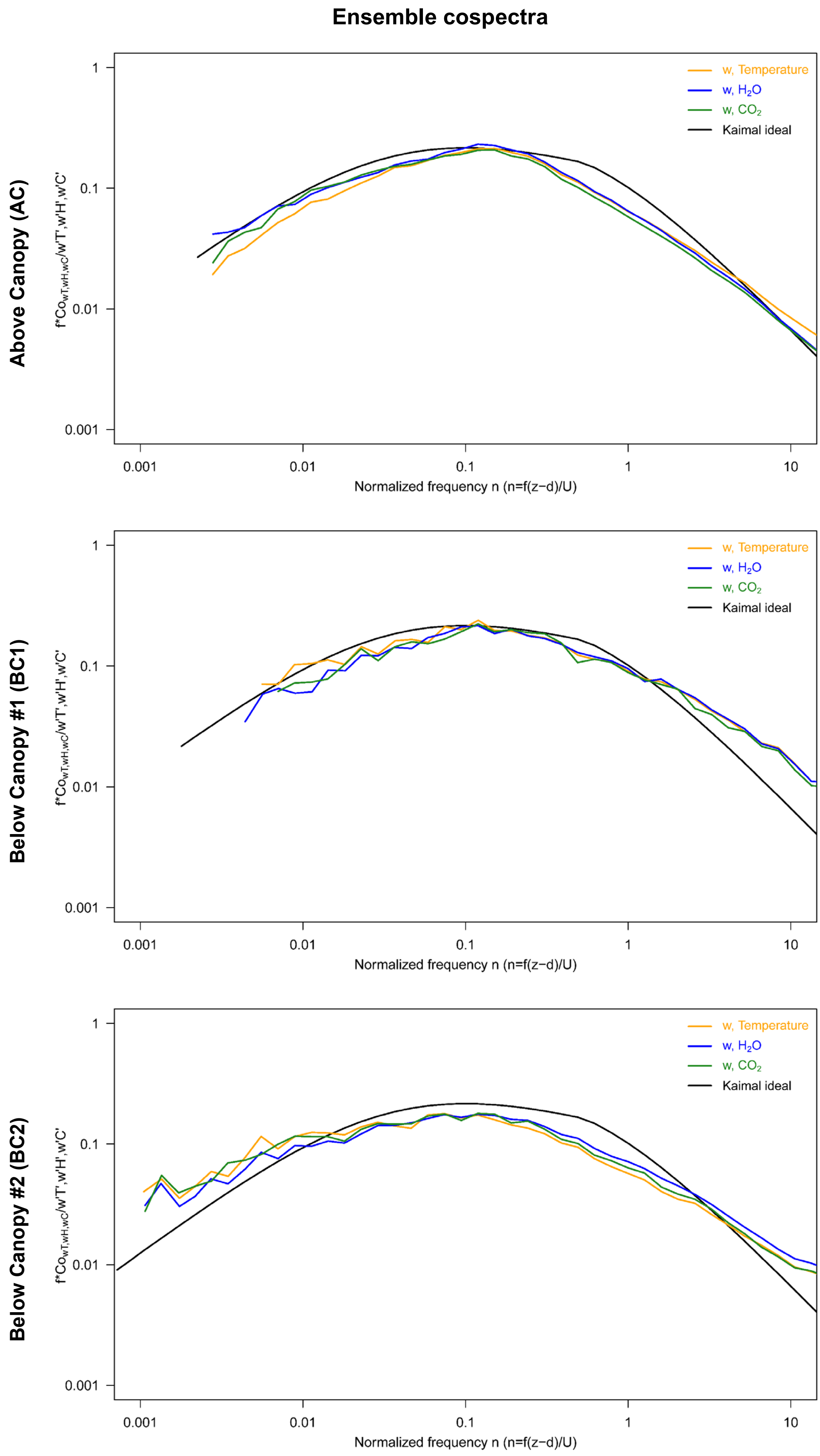

Figure S3. Normalized ensemble cospectra of vertical wind (*w*) with temperature (*T*), water vapor (*H*) and carbon dioxide (*C*) concentrations at Sagehen from June to October 2019. The black line represents the ideal cospectral model for flat terrain by Kaimal et al. (1972). The normalized frequency (n) is derived from the measurement height above ground (z) minus the aerodynamic (*i.e.* zero-plane) displacement height (d), normalized by horizontal wind speed (U). Please note that both axes are logarithmic.

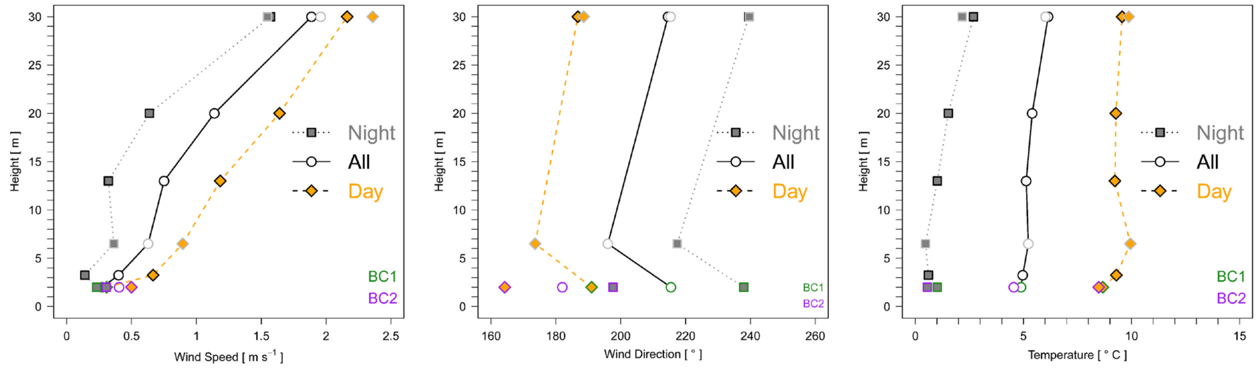

Figure S4. Profile measurements of mean daily wind speed, wind direction and air temperature at Sagehen from October 2017 to September 2020 (i.e., full water years 2018–2020). Symbols outlined in grey instead of black denote measurements by WRCC-DRI at heights of 6.50 m and 30 m, which are measured by different instruments (RM Young 05103 Wind Monitor and Vaisala HMP45AC). Below-canopy tower #1 (BC1, symbol outlined in green) is displayed as part of the profile (*i.e.* bottom end of lines) due to its closer location to the above-canopy tower (AC), although below-canopy tower #2 (BC2, symbol outlined in purple) is displayed for reference as well.

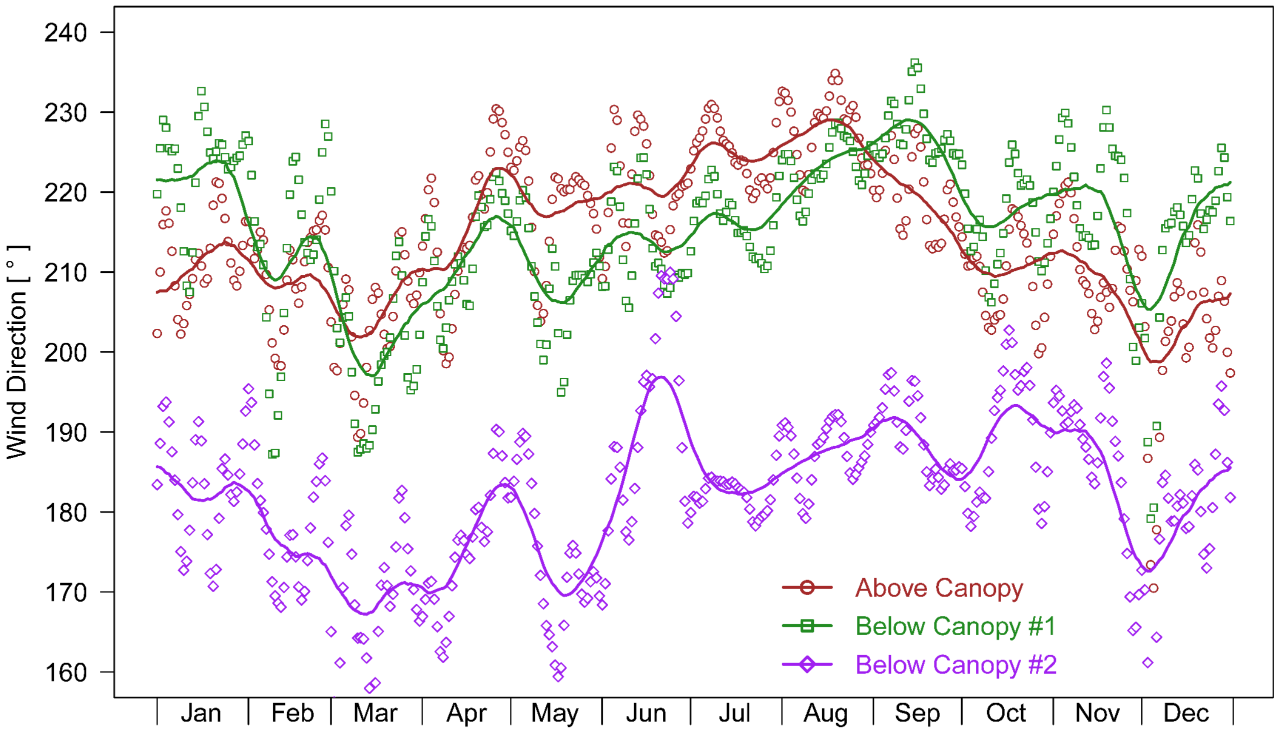

Figure S5. Mean seasonal cycle of daily wind direction at Sagehen from October 2017 to September 2020. Points denote 7-day running means and lines denote 30-day running means. Only minor directional wind shear (*i.e.* difference) was observed between the above-canopy tower (215±3°) and below-canopy tower #1 (BC1, 216±3°), which are both located within ~20 m of the creek and are thus situated along the bottom of the west-east oriented valley. However, a pronounced mean wind shear of about 35° was measured between the above-canopy tower and below-canopy tower #2 (BC2, 181±7°) towards the south. This is likely related to (i) the larger distance of BC2 from the creek (~60 m towards the south), to (ii) topography-related differences in wind fields within the Sagehen valley, and to (iii) the more open vegetation cover near BC2, with a large open meadow just south of the BC2 tower (see Figure S1), resulting in lower surface roughness. Additional evidence for (i) and (ii) are higher nighttime frequencies in wind direction along the creek (BC1) or towards the creek (BC2), indicating katabatic flow along the orographic slope, and additional evidence for (iii) is the higher wind speed observed at BC2 compared to BC1 (see Figures S6 & S7).

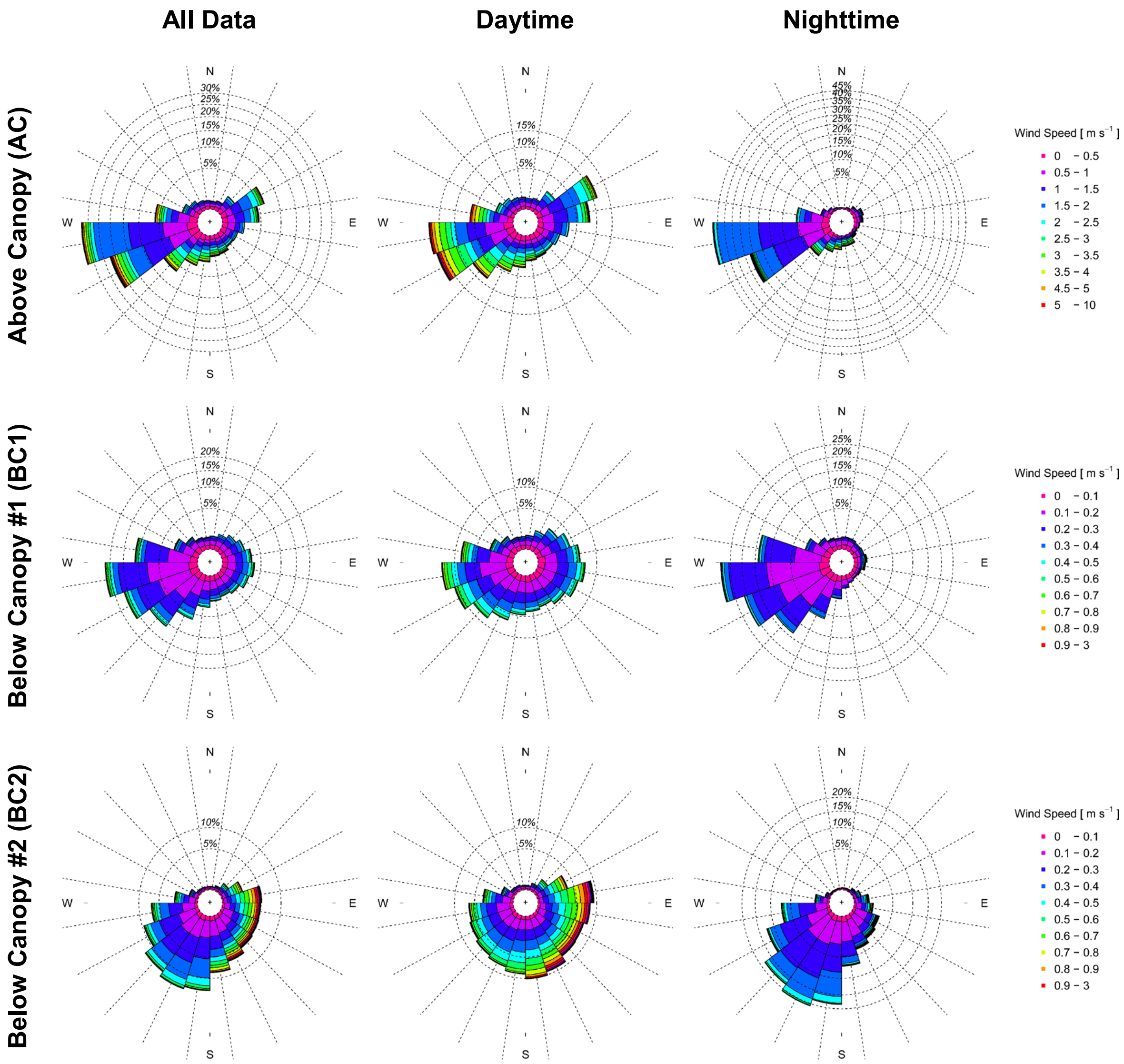

Figure S6. Wind roses of half-hourly wind direction (°) and wind speed (m s^{-1}) measured above and below canopy at Sagehen from June 2017 to September 2020. The radial scale denotes the percent contribution over the measurement period. Please note the different radial scaling for above canopy (AC) at nighttime.

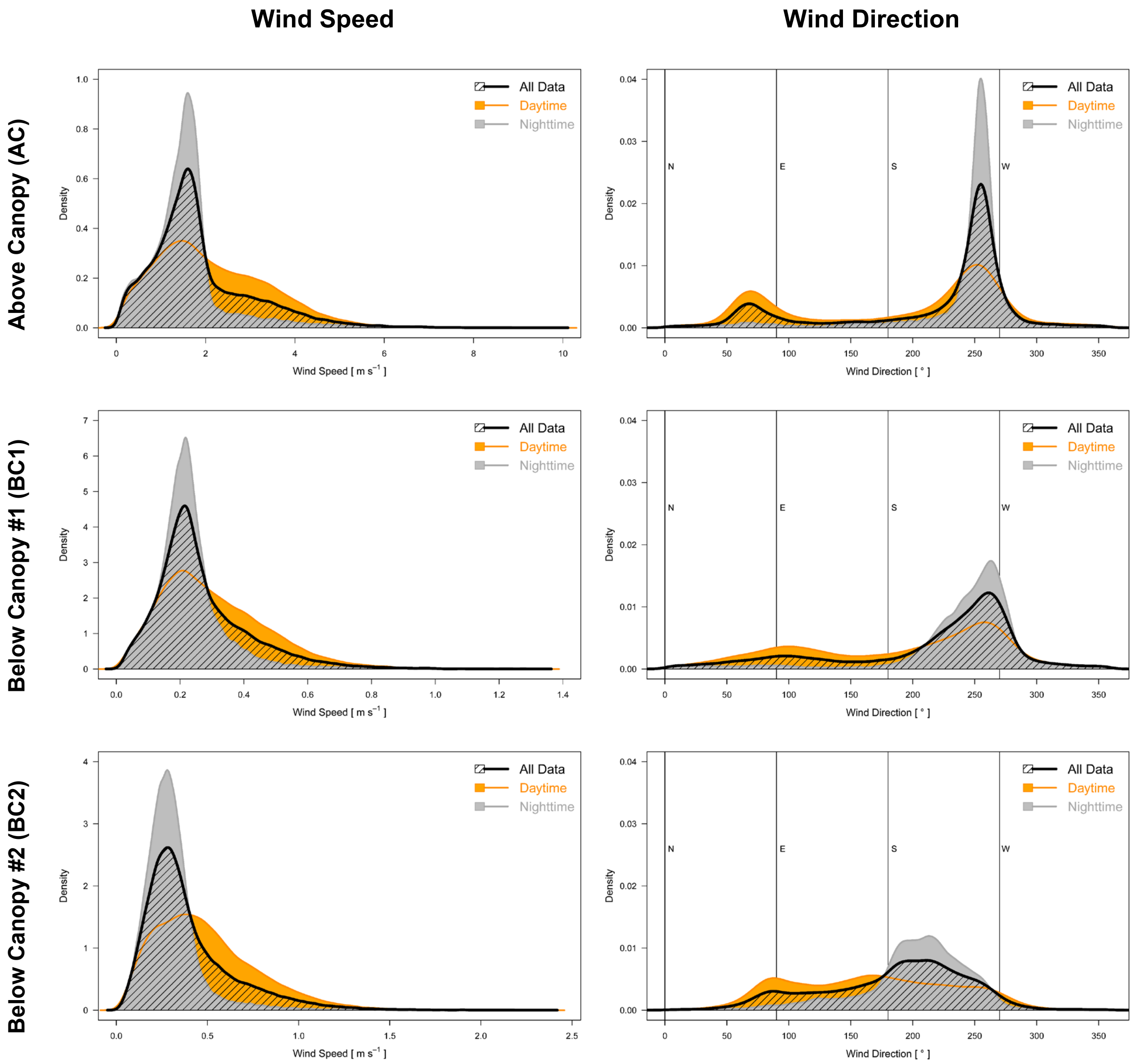

Figure S7. Density distributions of half-hourly wind speed and direction measured above and below canopy at Sagehen from June 2017 to September 2020. Please note the different axis scaling for wind speed between sites. Vertical lines denote the cardinal wind directions for reference.

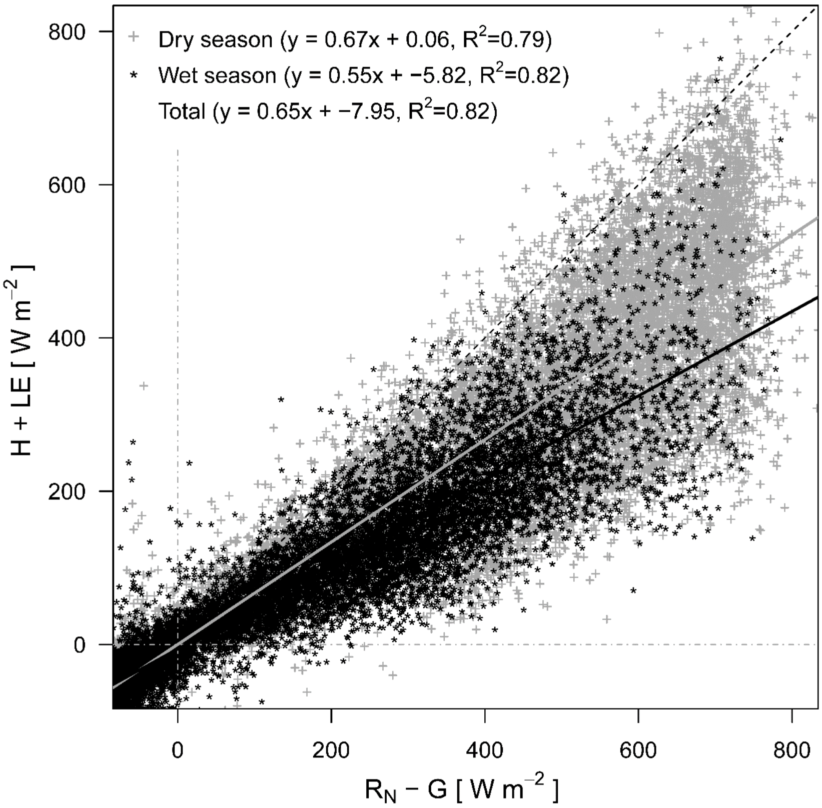

Figure S8. Energy balance closure analysis of half-hourly data comparing radiative (net radiation R_N – soil heat flux G) and turbulent measurements (sensible heat flux H + latent heat flux LE) of available energy above canopy at Sagehen. Grey and black symbols indicate the dry (May to September) and wet (October to April) seasons, respectively. The dashed black line denotes ideal closure (1:1), the solid grey line indicates the best fit for the dry season and the black line indicates the best fit for the wet season. The dashed grey lines are for visual reference of the zero values.

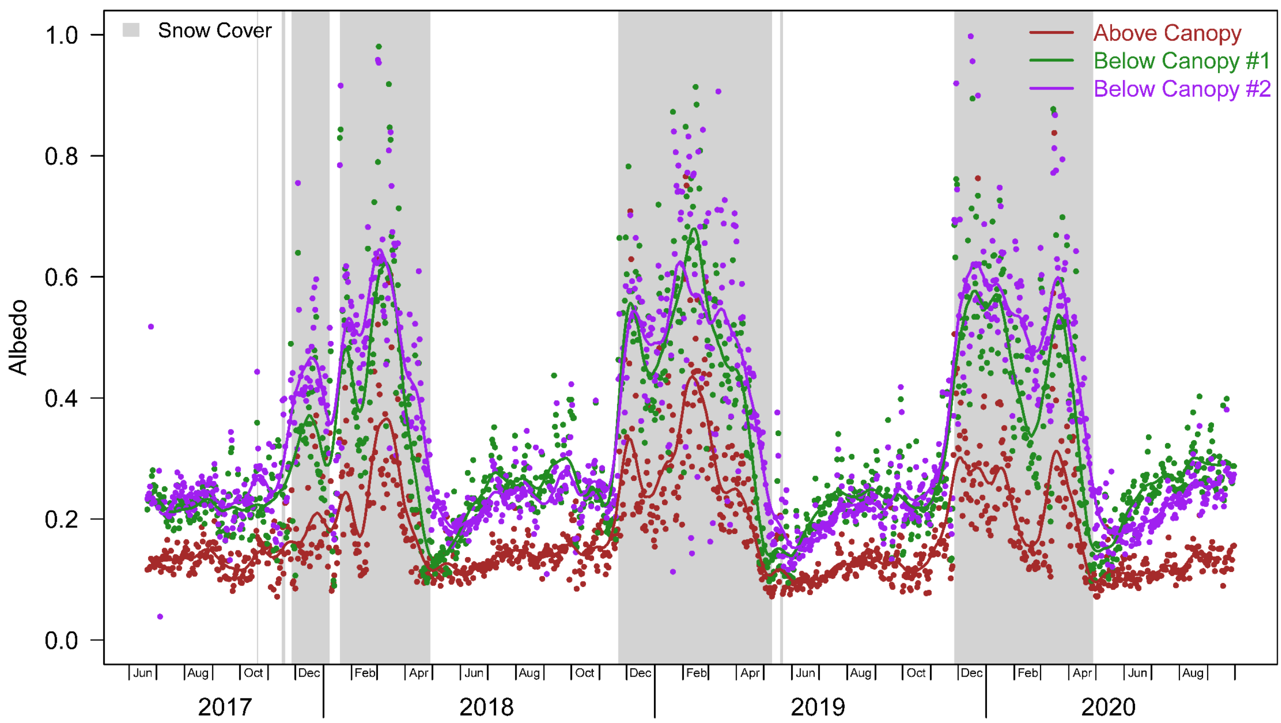

Figure S9. Daily mean albedo measured above the canopy (AC) and at the two below-canopy flux towers (BC1 and BC2) for 2017–2020. Lines denote 30-day running means. Grey shaded areas denote periods of snow cover on the ground as derived from PhenoCam imagery at BC2.

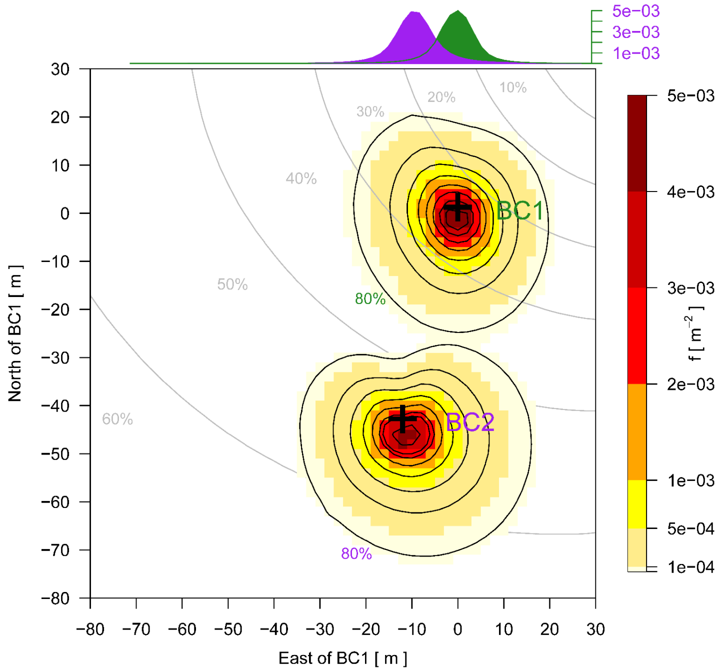

Figure S10. Footprint climatology of daytime turbulent exchange after Kljun et al. (2015) for below-canopy (BC1 and BC2) measurements at Sagehen Creek Field Station from 21 June 2017 to 30 September 2020. Contour lines denote cumulative source area contributions (in steps of 10%), in black for BC1 and BC2 and in gray for the above-canopy (AC) tower. Black cross marks indicate the location of the below-canopy towers (Note: the AC location is outside the displayed scaling range). The color range shows densities of source contributions (*i.e.* '*heat map*' of footprint function values) normalized per square meter (m^{-2}), with histograms of the maximum West-East densities displayed at the top. The colors of the histograms correspond to the colors of the tower name, i.e., green for BC1 and purple for BC2.

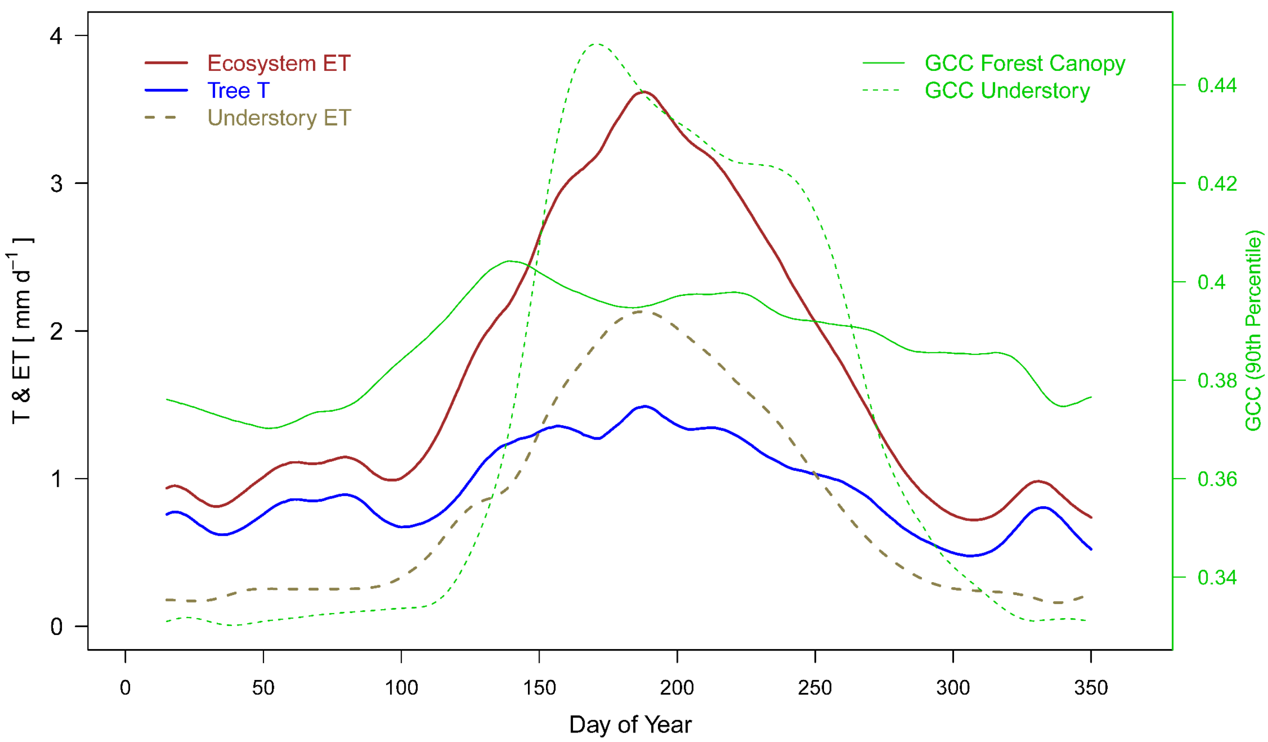

Figure S11. Mean seasonal cycle of daily total ecosystem evapotranspiration (ET), understory ET measured below canopy, partitioned tree transpiration (T), and vegetation activity from phenological observations of green chromatic coordinate (GCC) at the 90th percentile for 2017–2020. Lines denote 30-day running means.

Table S1 Effects of canopy interception and evaporation (E) from wet tree surfaces (*i.e.* leaves and branches) on annual and seasonal T/ET ratios (in %) of tree transpiration (T) and above-canopy measured evapotranspiration (ET) at Sagehen Creek Field Station during the water years (Oct.–Sep.) 2018–2020. The effects are quantified by excluding days with precipitation (P) and the following 1–5 days, assuming that E will become negligible and that T will dominate ET afterwards. Columns denote all data, including days with P (ALL), excluding days with P (woPD), and excluding days with P and the following 1–5 days (woPD+1 through woPD+5, respectively).

Year	Season	Period	T/ET [%] ALL	T/ET [%] woPD	T/ET [%] woPD+1	T/ET [%] woPD+2	T/ET [%] woPD+3	T/ET [%] woPD+4	T/ET [%] woPD+5
2018	Water Year	Oct. – Sep.	55	50	49	48	47	47	46
	Wet season	Oct. – Apr.	73	69	67	66	65	63	62
	Dry season	May – Sep.	45	44	45	44	44	44	44
2019	Water Year	Oct. – Sep.	55	49	47	46	45	45	45
	Wet season	Oct. – Apr.	75	69	65	64	63	63	62
	Dry season	May – Sep.	46	44	43	43	42	42	42
2020	Water Year	Oct. – Sep.	53	51	50	50	49	49	49
	Wet season	Oct. – Apr.	69	64	63	61	59	59	59
	Dry season	May – Sep.	46	46	46	46	46	46	46
2018–2020#	Water Year	Oct. – Sep.	54±1	50±1	49±2	48±2	47±2	47±2	47±2
	Wet season	Oct. – Apr.	72±3	67±3	65±2	64±2	63±3	62±2	61±2
	Dry season	May – Sep.	46±1	45±1	45±1	45±1	44±2	44±2	44±2

values indicate the mean ± standard deviation

Table S2 Averages of partitioned components of evaporation (E) and transpiration (T) relative to total forest evapotranspiration (ET) and total precipitation (P) at Sagehen Creek Field Station during the water years 2018–2020 (see *Sections 2.6 and 3.6*).

Component	Total [mm yr^{-1}]	relative to ET [%]	relative to P [%]
ET	606	100	68
P	895	148	100
Total E	156–197	26–33	17–22
E_{Tree} (interception)	44	7	5
$E_{Understory}$ from sublimation (snow)	30	5	3
$E_{Understory}$ (non-snow)	82–123	14–20	9–14
Total T	409–450	67–74	46–50
T_{Tree}	286	47	32
$T_{Understory}$ (grass)	123–164	20–27	14–18

References

Kaimal, J.C., Wyngaard, J.C., Izumi, Y. and Coté, O.R., 1972. Spectral characteristics of surface-layer turbulence. Quarterly Journal of the Royal Meteorological Society, 98(417): 563-589.

Kljun, N., Calanca, P., Rotach, M.W. and Schmid, H.P., 2015. A simple two-dimensional parameterisation for Flux Footprint Prediction (FFP). Geosci. Model Dev., 8(11): 3695-3713.