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Partitioning of canopy and soil CO_2 fluxes in a pine forest at the dry timberline across a 13-year observation period

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Table S1 | Monthly mean values of net ecosystem exchange (NEE), gross primary production (GPP), and ecosystem respiration (Re) and soil respiration (Rs) during study period. Note: the numbers in parenthesis is the ±se.

Season	**Month**	**NEE**	**GPP**	**Re**	**Rs**
		[μmol m^{-2} s^{-1}]			
Wet season (Nov-Apr)	Nov	-0.25 (0.10)	-0.81 (0.10)	0.56 (0.03)	0.78 (0.01)
	Dec	-0.48 (0.05)	-1.08 (0.04)	0.59 (0.01)	0.57 (0.01)
	Jan	-0.94 (0.11)	-1.96 (0.11)	1.02 (0.02)	0.91 (0.01)
	Feb	-1.52 (0.19)	-3.58 (0.20)	2.06 (0.03)	1.52 (0.02)
	Mar	-2.23 (0.17)	-4.65 (0.17)	2.42 (0.02)	1.54 (0.01)
	Apr	-1.32 (0.13)	-3.98 (0.13)	2.66 (0.02)	1.40 (0.01)
	Average [μmol m^{-2} s^{-1}]	**-1.12 (0.30)**	**-2.68 (0.66)**	**1.55 (0.38)**	**1.12 (0.17)**
	Season sum [g C m^{-2}]	**-203 (9)**	**-482 (20)**	**279 (11)**	**202 (5)**
	Rs/Re [%]				**72 (13)**
Dry season (May-Oct)	May	-0.55 (0.08)	-2.23 (0.08)	1.67 (0.02)	1.20 (0.01)
	Jun	0.50 (0.04)	-0.90 (0.04)	1.40 (0.02)	0.61 (0.01)
	Jul	0.29 (0.04)	-0.77 (0.03)	1.06 (0.01)	0.36 (0.01)
	Aug	0.45 (0.05)	-0.63 (0.04)	1.08 (0.02)	0.24 (0.01)
	Sep	0.25 (0.04)	-0.60 (0.04)	0.85 (0.02)	0.30 (0.01)
	Oct	0.26 (0.03)	-0.50 (0.02)	0.76 (0.01)	0.30 (0.01)
	Average [μmol m^{-2} s^{-1}]	**0.20 (0.16)**	**-0.94 (0.26)**	**1.14 (0.14)**	**0.50 (0.15)**
	Season sum [g C m^{-2}]	**36 (5)**	**-173 (8)**	**209 (4)**	**93 (5)**
	Rs/Re [%]				**44 (7)**
Annual	**Average (SE) [μmol m^{-2} s^{-1}]**	**-0.46 (0.26)**	**-1.81 (0.43)**	**1.34 (0.20)**	**0.8 (0.1)**
	Annual sum (SE) [g C m^{-2} y^{-1}]	**-167 (8)**	**-655 (13)**	**488 (6)**	**295 (4)**
	Rs/Re [%]				**60 (10)**

Table S2 | Exponential and linear relationships between soil respiration rate (Rs; µmol m^{-2} s^{-1}) and abiotic factors during 2015-2016. Ts (°C): soil temperature; SWC (m^3 m^{-3}): soil water content; PAR (µmol m^{-2} s^{-1}): incoming photosynthetic activity radiation above canopy. The best-fit model parameters (β_0, β_1, β_2, and β_3) are reported for each model together with the squared coefficient of regression (R^2), and the root mean squared error (RSME).

a) Up-scaled daily time series (the models that used during Grünzweig et al., 2009)

Model	Study	β_0	β_1	β_2	β_3	β_4	R^2
$\beta_0 + \beta_1\theta + \beta_2 PAR$	2000-2006	-2.306	25.39	0.000545			0.83
$\theta<0.2$ m^3 H_2O m^{-3} soil	2015-2016	-0.7313	11.14	0.000564			0.43
$\beta_0 + \beta_1 e^{\beta_2 Ts} + \beta_3 e^{\beta_4 PAR}$	2000-2006	1.394	0.1463	0.151	0.008408	0.003154	0.86
θ θ<0.2 m^3 H_2O m^{-3} soil	2015-2016						0.70

b) Up-scaled half-hour time series

Model	β_0	β_1	β_2	β_3	R^2	SSE
$\beta_0 + \beta_1 Ts$	1.264	-0.02			0.07	0.556
$\beta_0 e^{\beta_1 Ts}$	1.309	-0.02			0.07	0.558
$\beta_0 + \beta_1\theta$	0.2934	5.57			0.35	0.4667
$\beta_0+\beta_1\theta+\beta_2\theta^2$	-0.2175	17.47	-48.35		0.42	0.4388
$e^{\beta_0+\beta_1\theta+\beta_2\theta^2}$	-1.68	23.49	-67.3		0.44	0.4378
$\beta_0 + \beta_1 PAR$	0.7121	0.0002			0.05	0.5603
$\beta_0+\beta_1\theta+\beta_2 Ts$	-0.4213	7.626	0.02473		0.40	0.4499
$\beta_0+\beta_1\theta+\beta_2 PAR$	0.1162	5.989	0.00028		0.44	0.4295
$\beta_0\beta_1^{((Ts-10)/10)}\theta^{\beta_2}$	6.714	1.655	1.083		0.52	0.4151
$(\beta_0/(1+e^{\beta_1*(\beta_2-Ts)}))*\theta^{\beta_3}$	11.91	0.267	12.04	0.9908	0.54	0.3914
$(\beta_0/(1+e^{\beta_1*(\beta_2-PAR)}))*\theta^{\beta_3}$	90.12	0.0004	8625	0.6838	0.50	0.4169
$\beta_0 e^{\beta_1 Ts} e^{\beta_2\theta+\beta_3\theta^2}$	0.05126	0.04274	28.51	74.44	0.60	0.3932

Table S3 | Annual heterotrophic respiration (Rh), autotrophic respiration (Ra), soil respiration (Rs), ecosystem respiration (Re), gross primary productivity (GPP), net primary productivity (NPP), net ecosystem production (NEP; from eddy covariance), respectively. The relative contribution of Rh, and Ra and Rs to Re, and the ecosystem and soil carbon sequestration efficiency as CSE (NEP/GPP) and SCSE (ΔC_{soil}/GPP), where ΔC_{soil} is the annual change of soil carbon.

Study	**Rh**	**Ra**	**Rs**	**Re**	**GPP**	**NPP**	**NEP**	**Rh/Re**	**Ra/Re**	**Rs/Re**	**CSE**	**SCSE**
	[g m^{-2} y^{-1}]							**[%]**			**[%]**	
Semi-arid[1]	115	312	295	488	655	282	167	23	64	60	25	8.7
Europe, mean	368	589	657	957	1107	518	150	38	62	69	14	1.8
Europe[EN], mean	461	657	381	1117	1475	818	358	41	59	74	24	1.4
Boreal, global	301	561	411	862	982	381	116	35	65	48	12	0.7
Temperate, global	420	730	773	1150	1461	669	306	37	64	67	21	1.4
Tropical, global	877	2184	1412	3061	3351	864	403	29	71	46	12	0.3

[1] This study from November 2015 to October 2016. [EN] Evergreen needleleaf forests. References for all other vegetation types appear in the SI.

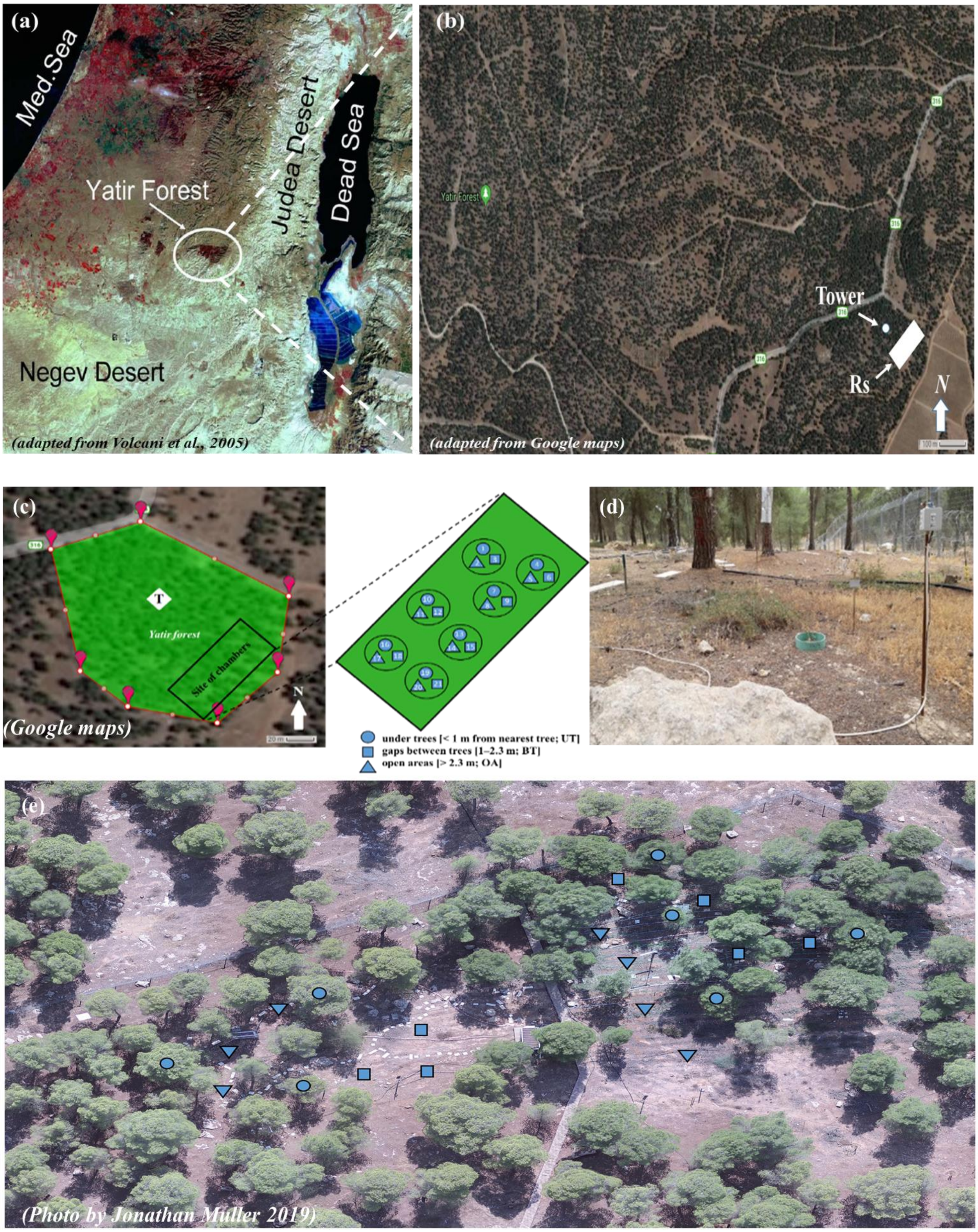

Figure S1 | (a) Landsat-TM image of Central Israel, (b) Map of the experimental set-up at the *Pinus halepensis* Yatir forest with white rectangle for soil respiration (Rs) measurements and white dot is the eddy covariance tower (NEE), c, d, and e) Photographs showing conditions of locations, site, and the schematic diagrams describing experiment design.

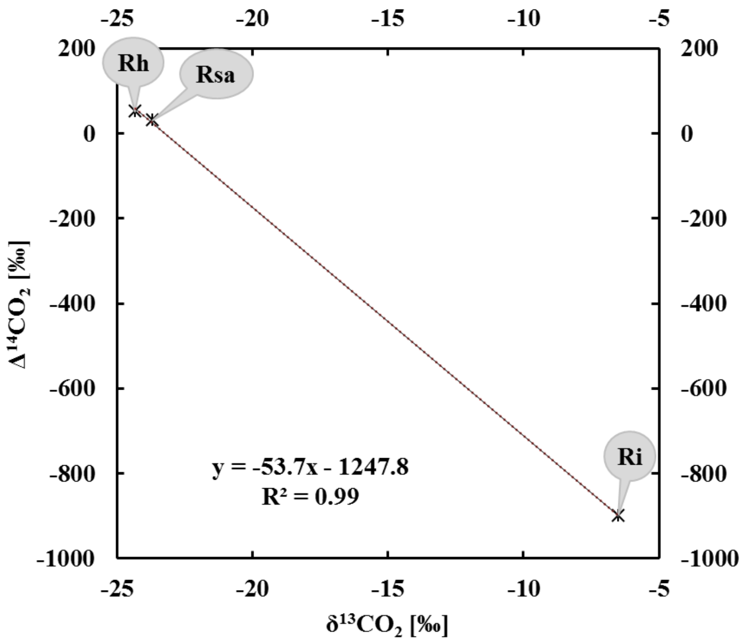

Figure S2 | The linear regression line used to estimate the $\Delta^{14}C$ of Rs. The line (dotted) was produced by the correlation between the average of the measured $\delta^{13}C$ values of Rsa, Rsh, and the $\delta^{13}C$ Ri (all from incubation measurements), and the $\Delta^{14}C$ values estimated based on measured $\Delta^{14}C$ at our site (Carmi et al. 2013) adjusted to the present study period and the mean accepted ages of autotrophic and heterotrophic soil organic material (Graven et al., 2012; Levin et al., 2010; Taylor et al., 2015).

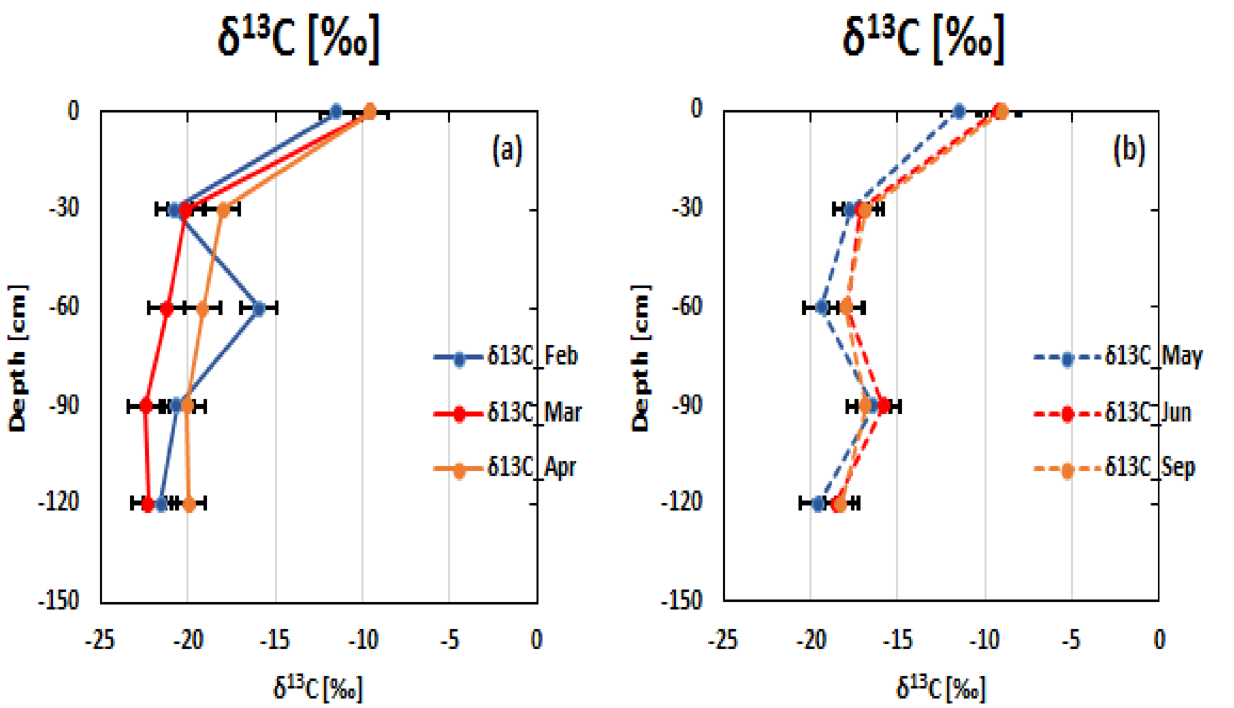

Figure S3 | Monthly averages of $\delta^{13}C$ (‰) from the soil CO_2 profile (at 0, 30, 60, 90, and 120 cm soil depth) during some campaigns in 2016 to determine the seasonal variations in the relative contribution of soil autotrophic (Rsa), heterotrophic (Rh), and abiotic (Ri) components to Rs.

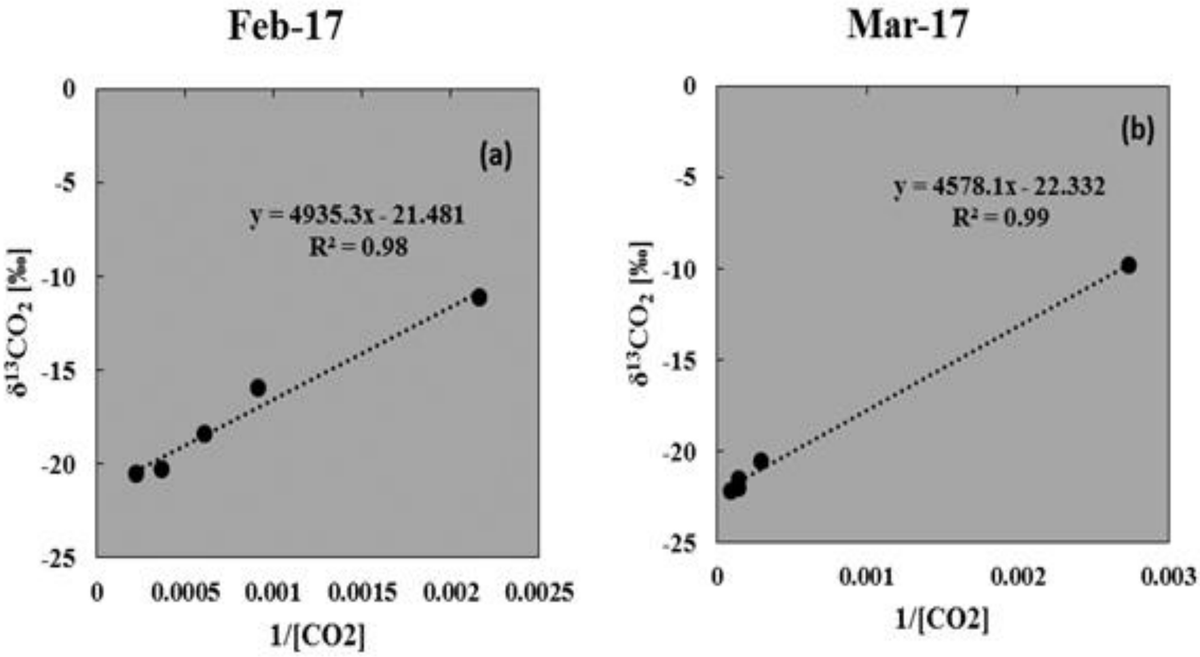

Figure S4 | Keeling plot for soil CO_2 profile (at 0, 30, 60, 90, and 120 cm soil depth) during some campaigns in 2016 to determine the seasonal variations in the relative contribution of soil autotrophic (Rsa), heterotrophic (Rh), and abiotic (Ri) components to Rs.

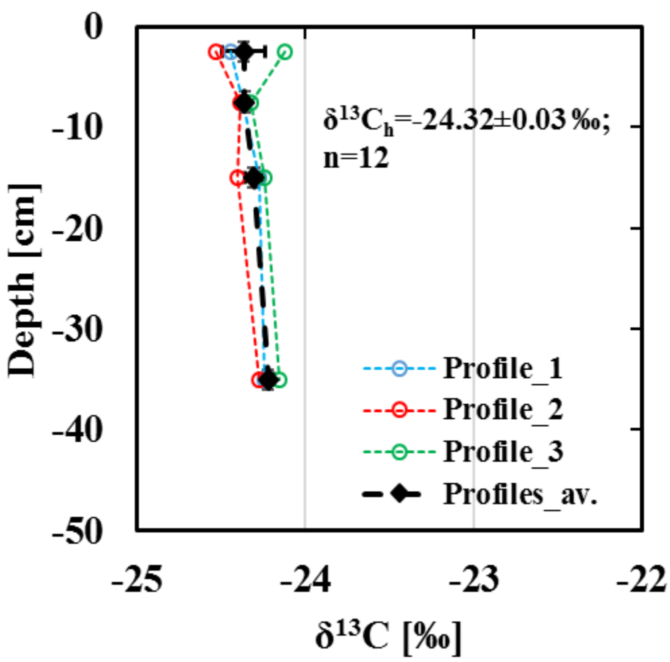

Figure S5 | $\delta^{13}C$ of soil organics profile with depth (at 0-5, 5-10, 10-20, and 20-50 cm soil depth) from three sites during some campaigns in 2016 to determine the relative contribution of soil heterotrophic (Rh) to Rs (STDEV of the 12 samples = 0.12‰).

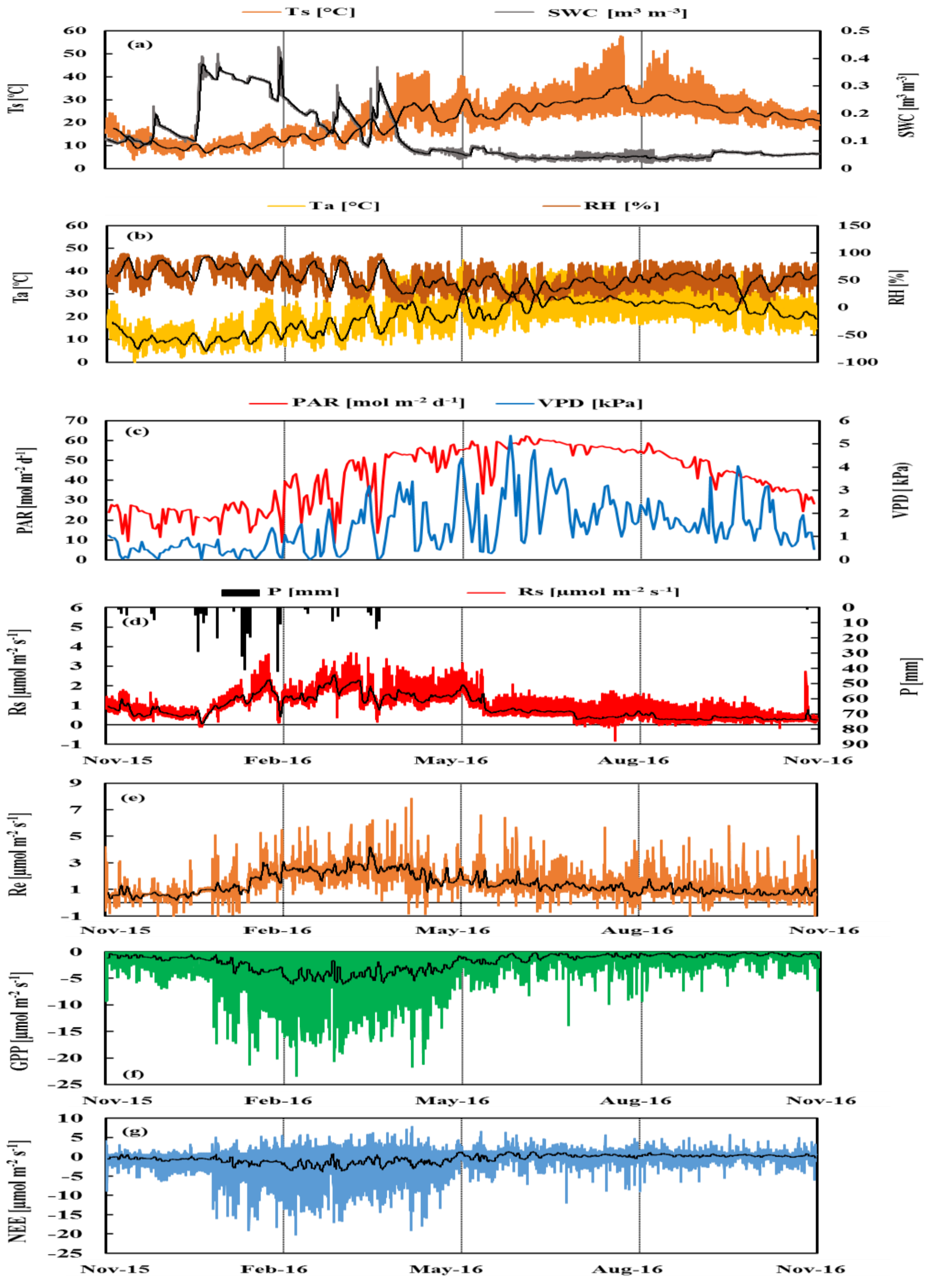

Figure S6 | a) half-hour values for soil temperature 5 cm (Ts) and soil water content 10 cm ($SWC_{0\text{-}10cm}$), b) half-hour values for the air temperature at 20 cm (Ta) and relative humidity at 20 cm (RH), c) daily average of incoming photosynthetic activity radiation above canopy (PAR) and vapour pressure deficit (VPD), half-hour values for the following CO_2 fluxes d) up-scaled Rs, e) ecosystem respiration (Re), f) gross primary production (GPP), and g) net ecosystem exchange (NEE). Black lines are a running average for a widows of 2 days. Vertical dotted lines indicate the winter, spring, summer and autumn seasons.

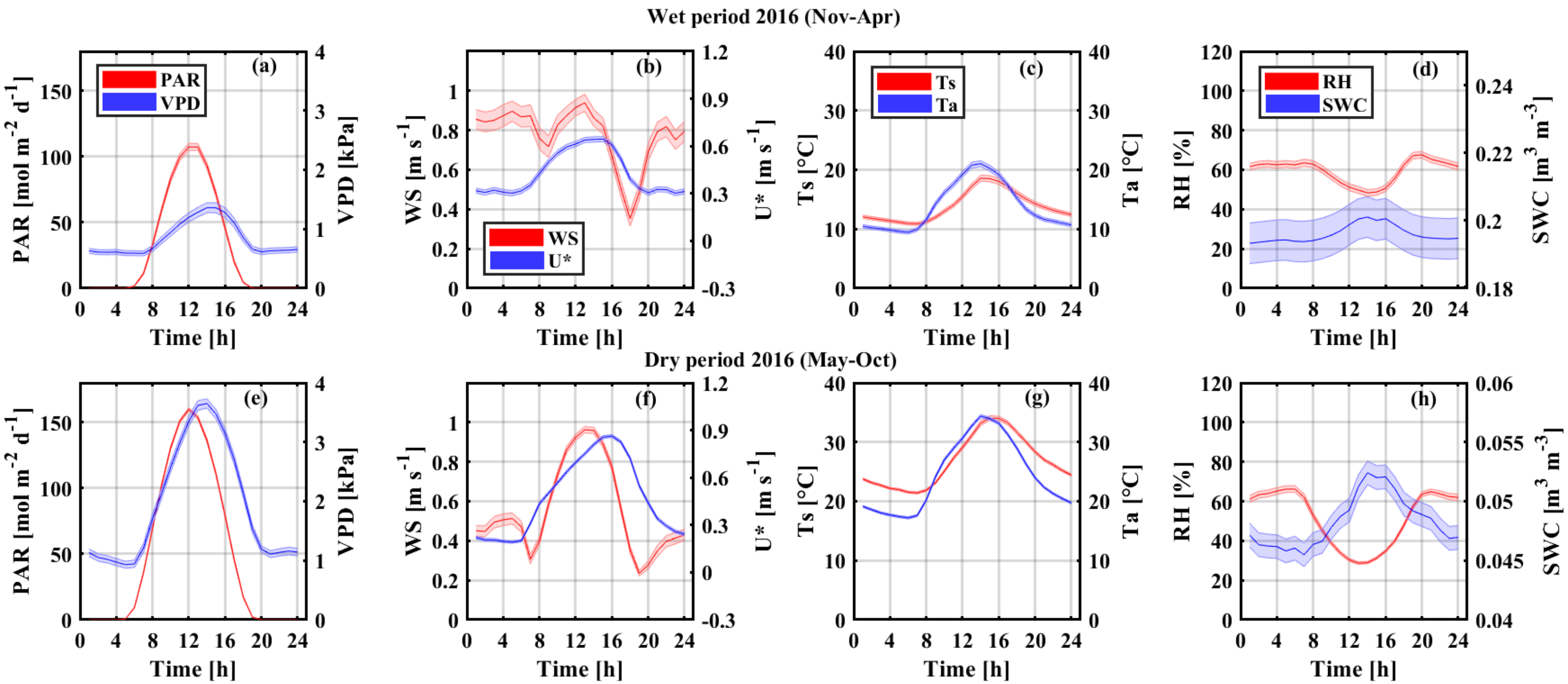

Figure S7 | Typical diurnal cycle of the meteorological parameters during the wet period (Nov.-Apr.; upper panels) and for the dry period (May-Oct.; lower panels); each set includes six months of half-hour measurements. a and e) incoming photosynthetic activity radiation above canopy (PAR) and vapour pressure deficit (VPD), b and f) wind speed (WS) and covariation of friction velocity (U*), c and g) soil temperature at 5 cm (Ts) and air temperature at 20 cm (Ta), and d and h) relative humidity (RH) and soil water content at the top 10 cm (SWC0-10cm). Shaded areas indicate ±se.

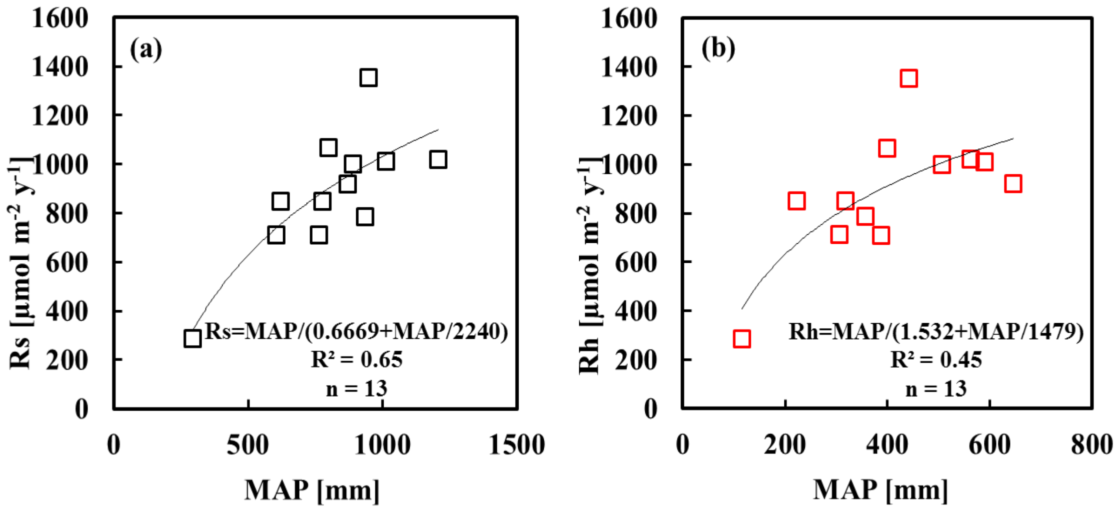

Figure S8 | An asymptotic function based on the Michaelis-Menten equation (Kool et al., 2007) was fit to a) Rs or b) Rh vs. MAP from the European Evergreen needleleaf data as follows: Rs = MAP/(0.6669 + MAP/2240), R^2 = 0.65, $p < 0.01$, n=13 (Flechard et al., 2019a).

Supplementary References (used for data in SI and Table S3)

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