Supplementary Methods

(1) ERA-Interim VPD

We calculated vapor pressure deficits (VPD) from the 0.125° spatial resolution land air temperature (T_a) and dew point temperature (T_d) ERA-Interim dataset, which is a reanalysis product based on the Integrated Forecast System of the European Centre for Medium-Range Weather Forecasts (ECMWF-IFS). The calculation (Dee et al. 2011) follows:

$$VPD = SVP - AVP$$

$$AVP = 6.112 \times f_w \times exp\left(\frac{17.67 \times T_d}{T_d + 243.5}\right)$$

$$SVP = 6.112 \times f_w \times exp\left(\frac{17.67 \times T_a}{T_a + 243.5}\right)$$

where SVP and AVP are saturated vapor pressure and actual vapor pressure (hPa), respectively. Ta and Td are the land air temperature (°C) and dew point temperature (°C), respectively.

$$f_w = 1 + 7 \times 10^{-4} + 3.46 \times 10^{-6} \times P_{mst}$$

$$P_{mst} = P_{msl} \times \left(\frac{(T_a + 273.16)}{(T_a + 273.16) + 0.0065 \times Z}\right)^{5.625}$$

where P_{mst} is the air pressure, P_{msl} is the air pressure at mean sea level (1013.25 hPa) and Z is the altitude.

(2) ERA5-Land 2m T_{air}

The ERA5-Land 2m air temperature data were supplied by the European Centre for Medium Range Weather Forecasts (ECMWF). ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5 (Zhao et al., 2020). This parameter is the temperature of air at 2m above the surface of land, sea or in-land waters. It is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. The units is kelvin (K) (Muñoz-Sabater et al., 2021).

(3) BESS SW

The Breathing Earth System Simulator (BESS) is a simplified process-based model that couples atmosphere and canopy radiative transfers, canopy photosynthesis, transpiration, and energy balance. It couples an atmospheric radiative transfer model and artificial neural network with forcings from MODIS atmospheric products.

(4) RTSIF

RTSIF dataset is in good agreement with the original TROPOMI SIF, and its accuracy is further validated against tower-based SIF (Chen et al., 2022). The TROPOspheric Monitoring Instrument (TROPOMI) on the Copernicus Sentinel-5P mission enables significant improvements in providing high spatial and temporal resolution SIF observations, but the short temporal coverage of the data records has limited its applications in long-term studies (Veefkind et al., 2012). RTSIF uses machine learning to reconstruct TROPOMI SIF for 2001-2020 with a spatial resolution of 0.05° and a temporal resolution of 8 days. We resample temporal resolution as monthly.

T_{air} and SW can be obtained directly from the relevant website. All of datasets used in this study are list in Table S3. The air temperature (T_{air}) grid files are available at website: https://rda.ucar.edu/datasets/ds314.3/. The ERA-Interim reanalysis datasets are available at website: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim. (Dee et al., 2011). The Breathing Earth System Simulator (BESS) incoming shortwave solar radiation (SW) grid files are available at website: http://environment.snu.ac.kr/bess_rad/. (Ryu et al. 2018). The reconstructed TROPOMI solar-induced fluorescence dataset (RTSIF) is available at website: https://doi.org/10.6084/m9.figshare.19336346.v2. (Chen et al., 2022). The MODIS Enhanced Vegetation Index (EVI) data are available at website: https://modis.gsfc.nasa.gov/data/dataprod/ mod13.php.

Supplementary Figure

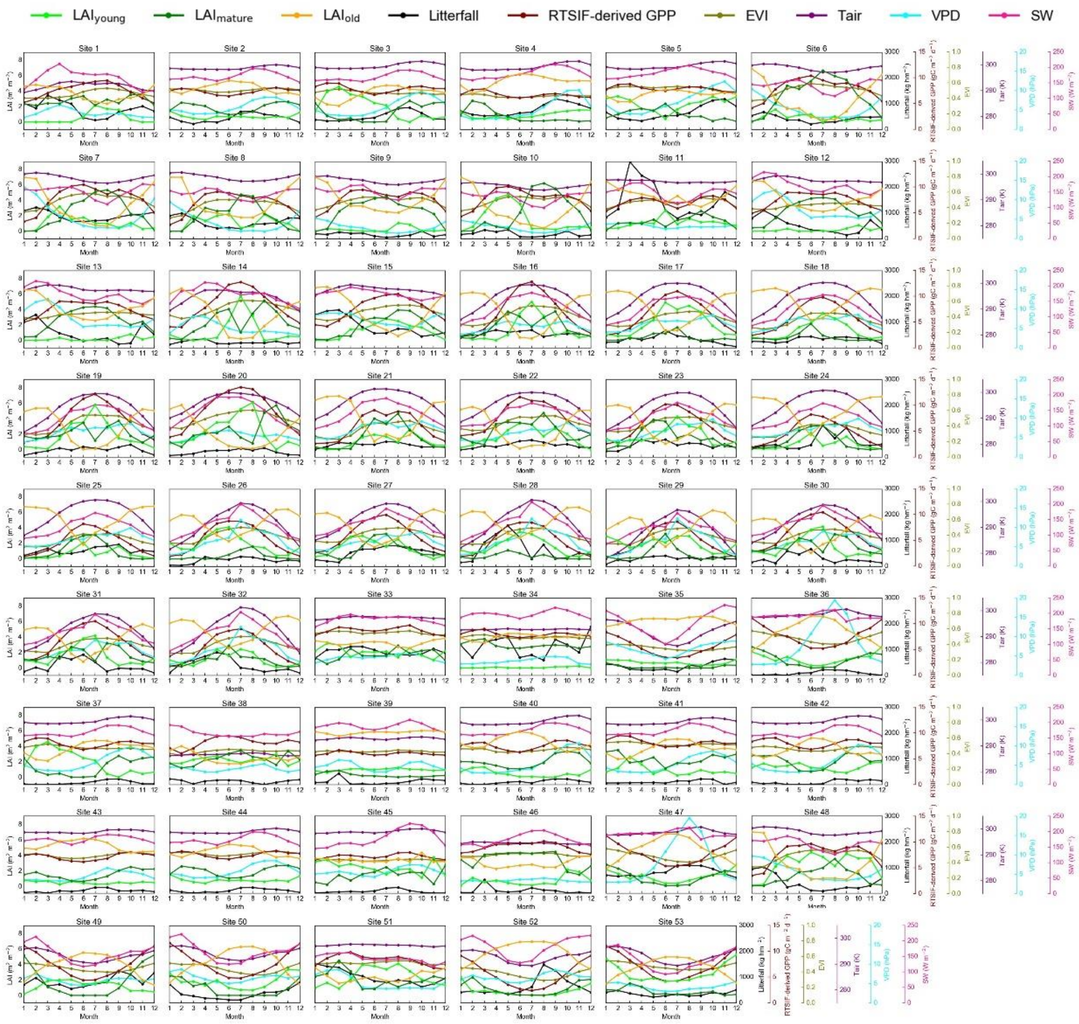

Figure S1 Seasonality of LAI_{young}, LAI_{mature}, LAI_{old}, litterfall, EVI, RTSIF-derived GPP, T_{air}, VPD and SW at 53 sites.

Supplementary Tables

Table S1 Information of three sites with observations of LAI cohorts

Site ID	Site Name	Latitude	Longitude
K67	Santarem-Km67-Primary Forest Ecosystem Research Station	-2.86	-54.96
K34	Manaus-K34 Forest Ecosystem Research Station	-2.61	-60.21
Dinghushan	Dinghushan Forest Ecosystem Research Station	23.17	112.54

Table S2 Information of four sites with observations of eddy covariance data

Site ID	Site Name	Latitude	Longitude
AU-Rob	Robson Creek, Queensland, Australia Forest Ecosystem Research Station	-17.12	145.63
BR-Sa1	Santarem-Km67-Primary Forest Ecosystem Research Station	-2.86	-54.96
BR-Sa3	Santarem-Km83-Logged Forest Ecosystem Research Station	-3.02	-54.97
GF-Guy	Guyaflux (French Guiana) Forest Ecosystem Research Station	5.28	-52.92

Table S3 Input grid datasets to calculate the net rate of CO_2 assimilation (An) in Figure 2.

Name abbr.	Datasets Name	Source	Sptial-resolution	Time-resolution	During
T_{air}	temperature	ERA5-Land	0.05deg	monthly	195001-202112
VPD	vapor pressure deficit	ERA-Land	0.125deg	monthly	198201-201812
SW	downward short wave radiation	BESS	0.05deg	daily	200101-201912
RTSIF	sun-induced chlorophyll fluorescence	TROPOMI-SIF	0.05deg	8days	200101-201812

Table S4 -part1 Equations for calculating An, W_c, W_j and W_p and intermediate variables in Figure 2.

Equations	Notes	Ref.
$A_n = \min\{w_c, w_j, w_p\} - R_{dark}$	Net carbon assimilation rate (A_n, μmol/m^2/s).	Farquhar et al., 1980; Bernacchi et al., 2013
$w_c = V_{c\max} \times \frac{c_i - \Gamma^*}{c_i + K_C \times (1 + \frac{O}{K_O})}$	Rubisco-limited photosynthetic rate (w_c, μmol/m^2/s)	Farquhar et al., 1980
$w_j = J \times \frac{c_i - \Gamma^*}{4 \times (c_i + 2 \times \Gamma^*)}$	Electron-transport limited rate of photosynthetic rate (w_j, μmol/m^2/s)	Farquhar et al., 1980
$J = \frac{J_e + J_{\max} - \sqrt{(J_e + J_{\max})^2 - 4 \times \Theta \times J_e \times J_{\max}}}{2 \times \Theta}$	The rate of electrons through the thylakoid membrane (μmol/m^2/s)	Farquhar et al., 1980; Bernacchi et al., 2013
$J_e = PAR_{total} \times \alpha \times \beta \times \Phi_{PSII}$	The rate of whole electron transport provided by light (μmol/m^2/s).	Bernacchi et al., 2013
$w_p = 0.5 \times V_{c\max}$	Triose phosphate export limited rate of photosynthesis (μmol/m^2/s)	Ryu et al., 2011
$Para = Para_{25} \times \exp(\frac{(T_K - 298.15) \times \Delta H_{para}}{R \times T_K \times 298.15})$	Temperature dependence function for various parameters including K_C, K_O ,Γ^* , R_{dark} and V_{cmax}. T_K denotes leaf temperature in Kelvin. Reference temperature is 25 ℃.	Bernacchi et al., 2013
$J_{\max} = J_{\max,25} \times \exp((\frac{25 - T_{opt}}{\Omega_T})^2 - (\frac{T_K - 273.15 - T_{opt}}{\Omega_T})^2)$	Temperature dependence function for maximum electron transport rate (J_{max}). T_{opt} is the optimal temperature for $J_{max.}$	Bernacchi et al., 2013; June et al., 2004
$g_s = 1.6 \times (1 + \frac{g_1}{\sqrt{VPD}}) \times \frac{A_n}{c_a}$ $A_n = g_s \times (c_a - c_i)$ $\Rightarrow c_i = c_a \times (1 - \frac{1}{1.6 \times (1 + \frac{g_1}{\sqrt{VPD}})})$	Use optimal stomatal model to estimate internal CO_2 concentration (c_i) from atmospheric CO_2 concentration (c_a) and vapor pressure deficit (VPD)	Lin et al., 2015; Medlyn et al., 2011

68 **Table S4 -part2** Equations for calculating An, W_c, W_j and W_p and intermediate
69 variables in Figure 2.

Symbol/Equations	Notes	Ref.
$c_a = 380$	Atmospheric CO_2 concentration (ppm)	
$g_1 = 3.77$	Coefficient in stomatal conductance scheme	Lin et al., 2015
$J_{\max,25} = 1.67 \times V_{c\max,25}$	Maximum electron transport rate (μmol/m^2/s) at 25 °C	Medlyn et al., 2002
$O = 210$	Atmospheric O_2 concentration (pp thousand)	
$R = 8.314$	Universal gas constant (J/K/mol)	
$T_{opt} = 35$	Optimal temperature for J_{max} (°C)	Lloyd and Farquhar, 2008
$K_{C,25} = 404.9$ $\Delta H_{K_C} = 79.43$	Michaelis-Menton constant for carboxylase (μmol/mol) at 25 °C and activation energy for temperature dependence (kJ/mol)	Bernacchi et al., 2001
$K_{O,25} = 278.4$ $\Delta H_{K_O} = 36.38$	Michaelis-Menton constant for oxygenase (mmol/mol) at 25 °C and activation energy for temperature dependence (kJ/mol)	Bernacchi et al., 2001
$R_{dark,25} = 0.015 \times V_{c\max,25}$ $\Delta H_{R_{dark}} = 46.39$	Leaf dark respiration (μmol/m^2/s) at 25 °C and activation energy for temperature dependence (kJ/mol)	Bernacchi et al., 2001
$V_{c\max,25}$ $\Delta H_{V_{c\max}} = 65.33$	Maximum carboxylation rate (μmol/m^2/s) at 25 °C is acquired from observations. Its activation energy for temperature dependence (kJ/mol) is listed	Bernacchi et al., 2001
$\Gamma^*_{25} = 42.75$ $\Delta H_{\Gamma^*} = 38.83$	CO_2 compensation point (μmol/mol) at 25 °C and activation energy for temperature dependence (kJ/mol)	Bernacchi et al., 2001
$\alpha = 0.85$	Leaf absorbance fraction of photosynthetically active radiation (PAR)	Farquhar et al., 1980; Bernacchi et al., 2013
$\beta = 0.5$	Fraction of PAR that reaches PSII system	Farquhar et al., 1980; Bernacchi et al., 2013
$\Phi_{PSII} = 0.85$	Maximum quantum efficiency of PSII photochemistry.	Bernacchi et al., 2003; Evans, 1989; von Caemmerer et al., 2000
$\Theta = 0.7$	Convexity of light-response curve.	Bernacchi et al., 2003; Evans, 1989; Ögren and Evans, 1993
$\Omega_T = 11.6 + 0.18 \times T_{opt}$	Coefficient for the temperature function of J_{max}. T_{opt} is optimal temperature for J_{max} (°C)	Bernacchi et al., 2003

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Table S4 -part3 Equations for calculating An, W_c, W_j and W_p and intermediate variables in Figure 2.

Equations to calculate radiative transfer within canopy with a total leaf area index as LAI_{total}.

Equations	Notes	Ref.
$PAR_{total} = (1-\rho_{cb}) \times PAR_{b,0} \times \left(1 - exp(-k'_b \times CI \times LAI_{total})\right) + (1-\rho_{cd}) \times PAR_{d,0} \times \left(1 - exp(-k'_d \times CI \times LAI_{total})\right)$	Total PAR absorbed by canopy (μmol/m^2/s)	He et al., 2012; Ryu et al., 2011; De Pury and Farquhar, 1997
$k'_b = \frac{0.46}{\cos(SZA)}$	Extinction coefficient for beam and scattered beam PAR	De Pury and Farquhar, 1997
$k'_d = 0.719$	Extinction coefficient for diffuse and scattered diffuse PAR	De Pury and Farquhar, 1997
$\rho_{cb} = 0.029$	Canopy reflection coefficient for beam PAR	De Pury and Farquhar, 1997
$\rho_{cd} = 0.036$	Canopy reflection coefficient for diffuse PAR	De Pury and Farquhar, 1997
$CI = 0.63$	Leaf clumping index	He et al., 2012; Ryu et al., 2011

Table S4 -part4 Equations for calculating An, W_c, W_j and W_p and intermediate variables in Figure 2.

Equations to calculate incoming photosynthetically active radiation in beam ($PAR_{b,0}$) and in diffuse ($PAR_{d,0}$) over canopy. R_{short} denotes total short-wave radiations from BESS SW. P denotes observed air pressure and P_0 denotes standard air pressure.

Equations	Notes	Ref.
$PAR_{b,0} = R_{short} \times f_{PAR} \times f_{PAR,b}$ $PAR_{d,0} = R_{short} \times f_{PAR} \times (1 - f_{PAR,b})$	The canopy top photosynthetically active radiation in beam ($PAR_{b,0}$) and diffuse ($PAR_{d,0}$) light	Weiss and Norman, 1985
$f_{PAR} = \frac{R_{b,vis} + R_{d,vis}}{R_{b,nir} + R_{d,nir} + R_{b,vis} + R_{d,vis}}$ $f_{PAR,b} = \frac{R_{b,vis}}{R_{b,vis} + R_{d,vis}} \times (1 - (\frac{0.9 - \frac{R_{short}}{R_{b,nir} + R_{d,nir} + R_{b,vis} + R_{d,vis}}}{0.7})^2)$	The fraction of total PAR over total incoming radiation (f_{PAR}) and the fraction of beam PAR over total PAR ($f_{PAR,b}$)	Weiss and Norman, 1985
$R_{b,vis} = \frac{600 \times e^{-0.185 \times \frac{P}{P_0} \times m}}{m}$	Expected beam visible radiation under clear sky (W/m^2)	Weiss and Norman, 1985
$R_{d,vis} = \frac{0.4 \times (600 - R_{b,vis} \times m)}{m}$	Expected diffuse visible radiation under clear sky (W/m^2)	Weiss and Norman, 1985
$R_{b,nir} = \frac{720 \times e^{-0.06 \times \frac{P}{P_0} \times m} - w}{m}$	Expected beam near-infrared radiation under clear sky (W/m^2)	Weiss and Norman, 1985
$R_{d,nir} = \frac{0.6 \times (720 - R_{b,nir} \times m - w)}{m}$	Expected diffuse near-infrared radiation under clear sky (W/m^2)	Weiss and Norman, 1985
$w = 1320 \times 10^{-1.195 + 0.4459 \times \log_{10} m - 0.0345 \times (\log_{10} m)^2}$	Expected water absorbance of near-infrared radiation in the atmosphere (W/m^2)	Weiss and Norman, 1985
$m = \cos(SZA)^{-1}$	Parameter calculated from solar zenith angle (SZA)	Weiss and Norman, 1985

Table S5. Information of 53 sites with ground-based observations of seasonal litterfall data.

Site	Latitude	Longitude	Reference
1	15.50	-90.45	Kunkelwestphal and Kunkel, 1979
2	-2.61	-60.21	Pastorello et al., 2020
3	-2.85	-54.95	Pastorello et al., 2020
4	-0.45	-51.70	Barlow et al., 2007
5	-1.73	-47.15	Dantas and Phillipson, 1989
6	6.85	4.35	Hopkins, 1966
7	7.48	4.57	Odiwe and Muoghalu, 2003
8	5.70	6.20	Ndakara, 2011
9	4.57	9.45	Songwe and Fasehun, 1995
10	4.37	9.27	Songwe and Fasehun, 1995
11	0.51	12.80	Midoka et al., 2019
12	8.48	77.28	Sundarapandian and Swamy, 1999
13	8.47	77.36	Sundarapandian and Swamy, 1999
14	21.93	101.27	CERN
15	14.50	101.92	Yamashita et al., 2010
16	22.13	106.82	Lu et al., 2008
17	21.93	108.35	Wu, 1991
18	22.97	108.35	Rong, 2009
19	23.01	108.59	Zeng, 2011
20	19.12	109.95	Wang, 2008
21	21.08	110.17	Ren et al., 1998
22	21.85	111.02	Ren et al., 1998
23	23.47	111.87	Chen and Wang, 1992
24	22.68	112.90	Zou et al., 2006
25	22.68	112.90	CERN
26	26.10	117.20	Wu, 2006

27	24.33	117.43	Pan et al., 2010
28	26.19	117.43	Yang et al., 2003
29	27.70	117.68	Lin et al., 1999
30	24.77	117.86	Liu et al., 2009
31	24.77	117.86	Tang, 2010
32	26.47	117.95	Zheng et al., 2011
33	4.97	117.80	Burghouts et al., 1992
34	-1.52	120.03	Triadiati et al., 2011
35	-27.33	152.75	Hegarty, 1991
36	-11.42	-55.33	Zhang et al., 2014
37	-2.85	-54.95	Rice et al., 2004
38	4.79	-74.20	Zhang et al., 2014
39	5.45	-61.88	Zhang et al., 2014
40	-1.00	-52.00	Zhang et al., 2014
41	-3.01	-54.97	Figuera et al., 2011
42	-2.00	-54.00	Zhang et al., 2014
43	-4.33	-62.47	Zhang et al., 2014
44	-2.57	-60.12	Wu et al., 2016
45	5.27	-52.92	de Weirdt et al., 2012
46	7.20	-75.34	Wu et al., 2016
47	-11.42	-55.33	Zhang et al., 2014
48	6.22	-5.03	Zhang et al., 2014
49	-23.14	-44.18	Silva-Filho et al., 2006
50	-21.02	-40.92	Jackson, 1978
51	9.38	-79.96	Zhang et al., 2014
52	-23.18	-46.87	Morellato, 1992
53	-25.18	-48.30	Scheer et al., 2009

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