Supplement of Geosci. Model Dev., 11, 1343–1375, 2018
https://doi.org/10.5194/gmd-11-1343-2018-supplement

Geoscientific
Model Development
Open Access

Supplement of

LPJmL4 – a dynamic global vegetation model with managed land – Part 1: Model description

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S1 Supplementary informations to the description of the LPJmL4 model

Fig. S1 gives a schematic overview of the model structure represented in LPJmL4. Fig. S2 to S4 provides further information about implemented processes in LPJmL4. Global time series of some key parameters estimated by LPJmL4 are given in Fig. S5. These time series of carbon stocks and fluxes and water fluxes show the high dynamics of the different parameters between the years. Furthermore, we provide a list of applications which have used the LPJmL model (Table S1). This represents not a complete list of all references with LPJmL applications, but it illustrates the range of fields for topical, spatial and temporal use of the model. Table S2 gives an overview of input variables and their references used by LPJmL4. In addition, we give a list of output variables (see Table S3) computed by LPJmL4 and provided via the Online-Database: http://pmd.gfz-potsdam.de/portal/ see: http://doi.org/10.5880/pik.2017.009. Complementary to the associated Schaphoff et al. (under Revision) we give a comprehensive list of parameters (Tables S4 to S14) used by the model and are described in Schaphoff et al. (under Revision). Additionally, we provide a list of equations (Table S15), which are described in detail by the associated manuscript.

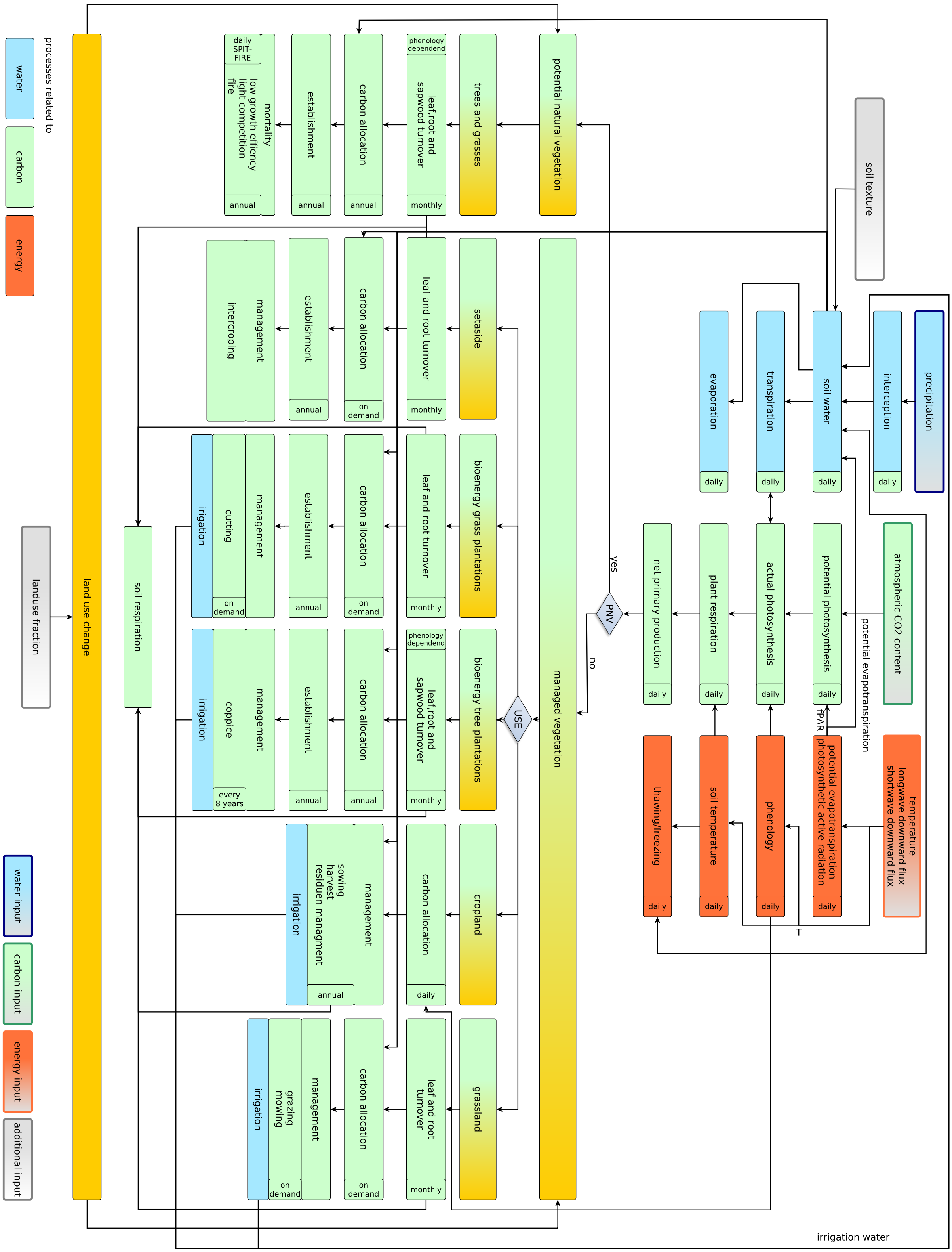

Figure S1. Flowchart describing the order of processes which are represented in the LPJmL4 model.

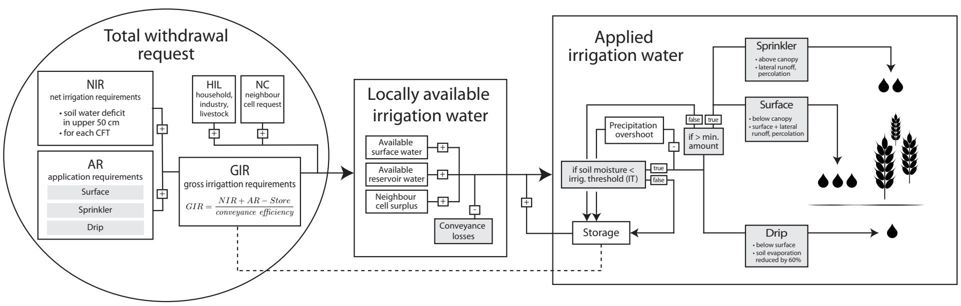

Figure S2. Irrigation water flows in LPJmL4 from plant-specific net irrigation requirement to actual field application. Variables represented in grey-shaded boxes depend on system-specific parameters that are presented in Table 2, adopted from Jägermeyr et al. (2015).

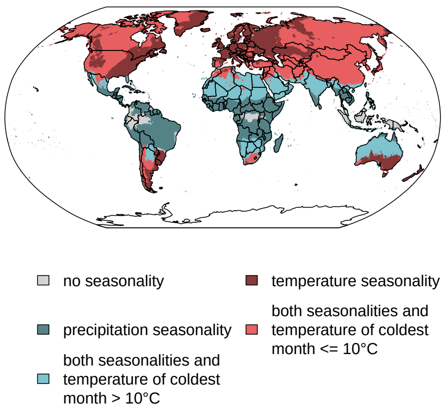

Figure S3. Seasonality types for sowing date calculated by LPJmL4.

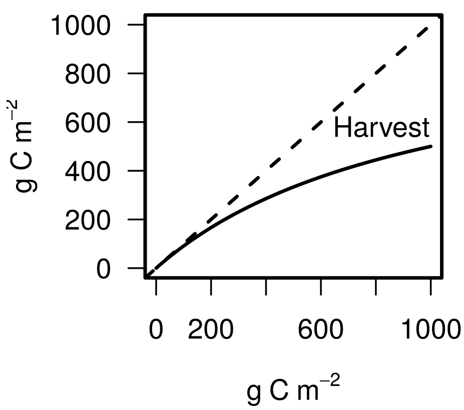

Figure S4. Leaf carbon (x-axis) that is remaining after harvest (solid line) and being harvested (between solid and dashed lines).

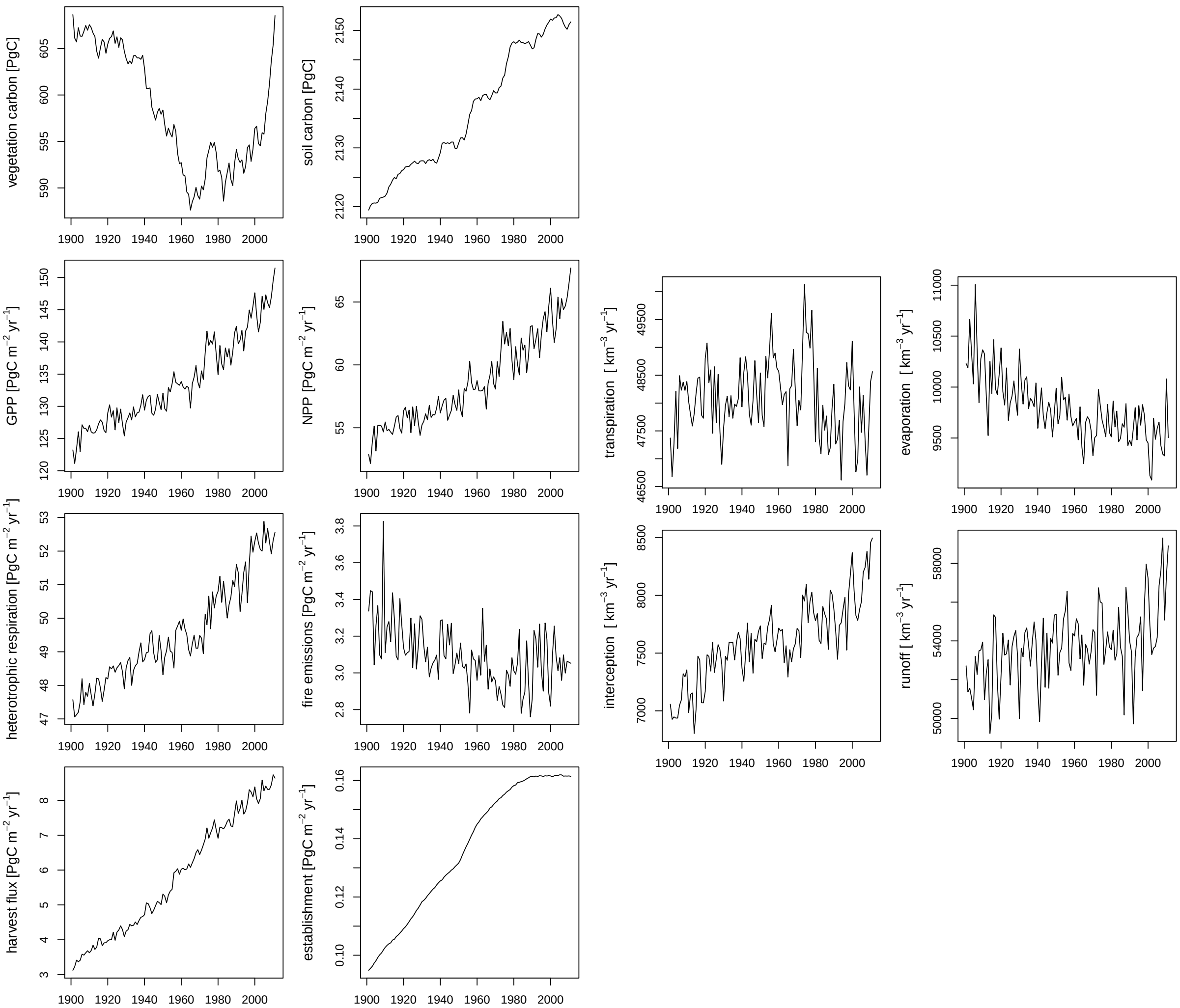

Figure S5. Time series of global carbon stocks and fluxes and global water fluxes computed by LPJmL4.

Table S1: Reference table of application using LPJmL since 2007.

Paper	Ecosystem processes					Carbon cycle							Water cycle			Agriculture				Temporal domain			Spatial domain			Type		
	Vegetation dynamics	Permafrost	Fire	Phenology	Albedo	Photosynthesis	Respiration	Fire emissions	Land C sink	Biomass	Soil carbon	Atmospheric composition	Evapotranspiration	Runoff, discharge	Human water use	Crops	Managed grassland	Agricultural trees	Bioenergy	Historic	Present and recent past	Future climate	Global	Regional	Site-level	Development	Evaluation	Application
Beer et al. (2007)	x	x	x	x																	x			x			x	x
Gerten et al. (2007)	x		x			x							x								x	x	x			x		x
Müller and Lucht (2007)						x	x	x	x	x	x		x	x							x		x				x	
Müller et al. (2007)									x							x						x	x					x
Gerten et al. (2008a)	x		x			x							x									x	x					x
Gerten et al. (2008b)														x							x				x		x	x
Jung et al. (2008)						x															x			x			x	x
Lotze-Campen et al. (2008)														x	x	x	x						x					x
Luo et al. (2008)	x		x			x	x			x	x		x									x	x		x		x	x
Rost et al. (2008)													x	x	x	x	x			x	x		x			x	x	x
Biemans et al. (2009)														x							x		x				x	
Lapola et al. (2009)																												
Pitman et al. (2009)	x			x	x				x				x			x	x			x	x		x					x
Poulter et al. (2009)				x		x															x			x			x	x
Rost et al. (2009)													x	x	x	x	x					x	x					x
Jung et al. (2010)													x								x		x				x	x
Von Bloh et al. (2010)														x							x		x			x		
Fader et al. (2010)													x		x	x					x	x	x			x		x
Gumpenberger et al. (2010)	x									x												x		x				x
Lotze-Campen et al. (2010)														x		x	x		x		x		x					x

Neumann et al. (2010)																x					x		x					x
Poulter et al. (2010a)	x					x			x	x												x		x	x			x
Poulter et al. (2010b)	x		x					x	x	x	x											x		x				x
Rammig et al. (2010)	x									x												x		x				x
Strengers et al. (2010)	x			x	x	x	x	x	x		x	x	x			x	x			x	x		x			x	x	x
Thonicke et al. (2010)			x					x	x												x					x	x	x
Beringer et al. (2011)																			x		x	x	x			x	x	x
Biemans et al. (2011)														x	x					x	x		x			x	x	x
Fader et al. (2011)													x		x	x	x				x		x					x
Franck et al. (2011)																x					x		x					x
Gerten et al. (2011)													x	x	x	x	x				x	x	x					x
Haberl et al. (2011)						x	x									x					x	x	x					x
Haddeland et al. (2011)													x	x							x		x				x	
Heyder et al. (2011)	x						x	x		x	x		x	x							x	x	x					x
Neumann et al. (2011)														x	x						x		x					x
Popp et al. (2011a)																x			x			x	x					x
Popp et al. (2011b)																			x			x	x					x
Poulter et al. (2011)									x												x		x					x
Jiang et al. (2012)	x																					x		x				x
Boisier et al. (2012)	x				x											x	x							x				x
de Noblet-Ducoudré et al. (2012)	x			x	x											x	x							x				x
Dietrich et al. (2012)																x							x					x
Souty et al. (2012)																x					x		x					x
Waha et al. (2012)																x					x		x			x	x	
Asseng et al. (2013)																x					x				x			x
Biemans et al. (2013)													x	x	x	x					x	x					x	x
Dass et al. (2013)									x							x			x		x	x	x					x
Fader et al. (2013)															x	x	x				x	x	x					x
Gerten et al. (2013b)	x					x	x			x	x		x	x	x							x	x					x

Gerten et al. (2013a)														x	x						x		x					x
Konzmann et al. (2013)															x	x					x	x	x				x	x
Langerwisch et al. (2013)														x								x		x		x	x	x
Ostberg et al. (2013)	x						x	x		x	x		x	x								x	x					x
Schaphoff et al. (2013)		x							x		x															x	x	x
Schierhorn et al. (2013)	x															x					x			x				x
Siderius et al. (2013)														x							x				x			x
Waha et al. (2013a)																x					x	x		x				x
Waha et al. (2013b)																x					x	x		x		x		x
Bassu et al. (2014)																x					x	x			x			x
Elliott et al. (2014)														x		x					x	x	x					x
Forkel et al. (2014)	x			x		x				x											x		x			x	x	
Jägermeyr et al. (2014)							x			x	x										x		x			x	x	
Kummu et al. (2014)															x	x	x			x			x					x
Müller and Robertson (2014)																x	x				x	x	x					x
Müller et al. (2014)						x								x		x					x	x		x				x
Piontek et al. (2014)	x	x	x						x					x		x					x	x	x					x
Rosenzweig et al. (2014)																x					x	x	x					x
Sakschewski et al. (2014)																x	x				x	x	x					x
Zscheischler et al. (2014a)									x														x				x	
Zscheischler et al. (2014b)									x														x				x	
Asseng et al. (2015)																x									x			x
Fader et al. (2015)											x				x	x		x						x		x	x	x
Forkel et al. (2015)	x			x																	x		x				x	x
Jägermeyr et al. (2015)													x	x	x	x					x		x			x	x	x
Kollas et al. (2015)																x					x				x			x
Martre et al. (2015)																x					x				x			x
Müller et al. (2015)																x					x	x	x					x
Ostberg et al. (2015)	x						x	x		x	x		x	x						x	x		x					x

Pirttioja et al. (2015)																x					x	x			x			x
Weindl et al. (2015)																x	x				x	x	x					x
Cammarano et al. (2016)													x			x					x				x		x	x
Deryng et al. (2016)																x							x					x
Forkel et al. (2016)	x					x			x			x															x	x
Jägermeyr et al. (2016)															x	x	x					x	x					x
Liu et al. (2016)																x					x	x	x		x			x
Müller et al. (2016)	x		x			x	x	x	x	x	x					x	x		x		x	x	x			x		x
Porkka et al. (2016)															x	x				x			x					x
Pugh et al. (2016)																x					x	x	x					x
Ruane et al. (2016)																x					x	x			x			x
Durand et al. (2017)						x								x		x						x		x				x
Maiorano et al. (2017)																x						x			x	x	x	x
Müller et al. (2017)						x								x		x				x				x				x
Jägermeyr et al. (2017)													x	x	x	x					x		x			x	x	x

Table S2. Model specific inputs applied by LPJmL4.

Input variables	Description	References
Precipitation	GPCC Full Data Reanalysis Version 7.0	Becker et al. (2013)
Temperature	CRU TS version 3.23	Harris et al. (2014); University of East Anglia Climatic Research Unit; Harris (2015)
Net downward long-wave radiation	ERA-Interim	Dee et al. (2011)
Shortwave downward radiation	ERA-Interim	Dee et al. (2011)
Number of wet days per months	synthetically derived	New et al. (2000)
Wind speed	NCEP re-analysis data	NOAA-CIRES Climate Diagnostics Center, Kalnay et al. (1996))
Landuse	MIRCA2000+ (see Fader et al. (2010))	Portmann et al. (2010); Monfreda et al. (2008); Siebert et al. (2015); Monfreda et al. (2008)
Soil texture	Harmonized World Soil Database (HWSD)	FAO/IIASA/ISRIC/ISSCAS/JRC (2012); Nachtergaele et al. (2009)
Drainage direction map	Topological Network (STN-30)	Vorosmarty and Fekete (2011)
Water reservoirs	GRanD database	Lehner et al. (2011)
Lakes	natural lakes	Lehner and Döll (2004)
Atmospheric CO_2 concentrations	NOAA/ESRL	Tans and Keeling (2015)

Table S3. Standard outputs computed by LPJmL4.

	Variable	Units
Carbon pools	Soil carbon	$gC\,m^{-1}$
	Litter carbon	$gC\,m^{-1}$
	Vegetation carbon	$gC\,m^{-1}$
	Above ground biomass	$gC\,m^{-1}$
Carbon fluxes	Monthly net primary production	$gC\,m^{-1}\,month^{-1}$
	Monthly gross primary production	$gC\,m^{-1}\,month^{-1}$
	Monthly soil respiration	$gC\,m^{-1}\,month^{-1}$
	Annual fire carbon emissions	$gC\,m^{-1}\,a^{-1}$
Water fluxes	Monthly interception	$mm\,month^{-1}$
	Monthly transpiration	$mm\,month^{-1}$
	Monthly evaporation	$mm\,month^{-1}$
	Monthly runoff	$mm\,month^{-1}$
	Monthly discharge	$hm^{-3}\,day^{-1}$
	Monthly grid cell albedo	-
	Monthly fraction of absorbed PAR	-
	Foliage projected cover	-
	Crop yields	$gC\,m^{-1}\,a^{-1}$
	Sowing dates	day of the year

Table S4. Model PFT-specific bioclimatic limits similar as in Sitch et al. (2003).

PFT	$T_{c,\min}$ (°C)	$T_{c,\max}$ (°C)	$T_{mort,\min}$ (°C)	$GDD_{\min}$ (°C)
TrBE	15.5	-	-	-
TrBR	15.5	-	-	-
TeNE	-2.0	22	-	900
TeBE	3.0	18.8	-	1200
TeBS	-17.7	15.5	-	1200
BoNE	-32.5	-2.0	23	600
BoBS	-	-2.0	23	350
BoNS	-46.5	-5.4	23	350
TrH	7.0	-	-	-
TeH	-39.0	15.5	-	-
PoH	-	-2.6	-	-

Table S5. PFT-specific albedo and light extinction values.

PFT	β_{leaf}	β_{stems}	β_{litter}	k	α_a
TrBE	0.14	0.10	0.10	0.5	0.4
TrBR	0.13	0.07	0.06	0.5	0.4
TeNE	0.137	0.04	0.10	0.4	0.4
TeBE	0.15	0.04	0.10	0.5	0.4
TeBS	0.15	0.04	0.10	0.6	0.4
BoNE	0.13	0.10	0.10	0.5	0.4
BoBS	0.18	0.10	0.10	0.5	0.4
BoNS	0.12	0.05	0.01	0.6	0.4
TrH	0.21	-	0.10	0.4	0.4
TeH	0.20	-	0.10	0.5	0.4
PoH	0.21	-	0.10	0.5	0.4
BTrT	0.13	0.04	0.10	0.6	0.8
BTeT	0.14	0.04	0.10	0.6	0.8
BGrC4	0.21	-	0.10	0.6	0.8
All crops	0.18	-	0.06	0.5	1.0

β_{leaf} is leaf albedo, β_{stems} is the albedo of stems, β_{litter} is albedo of litter, k is the light extinction coefficient in Lambert-Beer relationship, α_a is a scaling factor from leaf to ecosystem level (Haxeltine and Prentice, 1996). β_{leaf} as suggested by Strugnell et al. (2001), β_{stems} and β_{litter} parameters are determined by a tuning process described by Forkel et al. (2014).

Table S6. Global parameters and constants similar as in Sitch et al. (2003) and Schaphoff et al. (2013).

	Symbol	Value	Units	Description
Energy balance	c_{water}	4.2×10^6	$\mathrm{J\,m^{-3}\,K^{-1}}$	heat capacity of water
	c_{min}	1.9259×10^6	$\mathrm{J\,m^{-3}\,K^{-1}}$	heat capacity of mineral soil (De Vries, 1963)
	c_{ice}	2.1×10^6	$\mathrm{J\,m^{-3}\,K^{-1}}$	heat capacity of ice
Vegetation structure	k_{allom1}	100		Parameter for allometric relation ship Eq. 50
	k_{allom2}	40		Parameter for allometric relation ship Eq. 49
	k_{allom3}	0.67		Parameter for allometric relation ship Eq. 49
	$k_{\mathrm{la:sa}}$	4000		leaf area to sapwood area Eq. 47
	WD	20000	$\mathrm{gC\,m^{-3}}$	wood density Eq. 51
	k_{rp}	1.6		Reineke parameter Eq. 50
Photosynthesis	$[O_2]$	20900	Pa	O_2 partial pressure
	$K_{O_{25}}$	30000	Pa	Michaelis constant for O_2 at 25°C
	$K_{C_{25}}$	30	Pa	Michaelis constant for CO_2 at 25°C
	τ_{25}	2600		τ at 25°C
	$Q_{10_{K_O}}$	1.2		Q_{10} for temperature-sensitive parameter K_O
	$Q_{10_{K_C}}$	2.1		Q_{10} for temperature-sensitive parameter K_C
	Q_{10_τ}	0.57		Q_{10} for temperature-sensitive parameter τ
	α_{C_3}	0.08		intrinsic quantum efficiencies for CO_2 uptake in C_3 plants
	α_{C_4}	0.053		same for C_4 plants
	θ	0.7		Co-limitation (shape) parameter
	$\lambda_{\mathrm{max}_{C_3}}$	0.8		maximum ratio of intercellular to ambient CO_2 for C_3 plants
	$\lambda_{\mathrm{max}_{C_4}}$	0.4		same for C_4 plants
Plant respiration	b_{C_3}	0.015	rate per day	leaf respiration as fraction of V_m for C_3 plants
	b_{C_4}	0.035	rate per day	leaf respiration as fraction of V_m for C_4 plants
	$\mathrm{CN}_{\mathrm{sapwood}}$	330		C:N ratios for above-ground tissue
	$\mathrm{CN}_{\mathrm{root}}$	30		C:N ratios below-ground tissue
	r_{gr}	0.25		share of growth respiration
	k	0.0548	rate per day	respiration coefficient Eq. 42 (Sprugel et al., 1995)
Establishment and mortality	k_{est}	0.12	saplings $\mathrm{m^{-2}}$	establishment rate
	k_{mort1}	0.03	$\mathrm{a^{-1}}$	asymptotic maximum mortality rate
	k_{mort2}	0.2		coefficient of growth efficiency for mortality
	$\mathrm{tw}_{\mathrm{PFT}}$	400	°C	Parameter for heat damage function
Soil and litter decomposition	$\tau 10_{\mathrm{root,litter}}$	0.3	$\mathrm{a^{-1}}$	mean residence time of roots in litter Eq. 91
	$\tau 10_{\mathrm{root,fastSoil}}$	0.03	$\mathrm{a^{-1}}$	mean residence time of roots in fast soil carbon pool Eq. 91
	$\tau 10_{\mathrm{root,slowSoil}}$	0.001	$\mathrm{a^{-1}}$	mean residence time of roots in slow soil carbon pool Eq. 91

Table S7. PFT-specific parameters of litter turnover rates suggested by Brovkin et al. (2012) and shape factor for vertical distribution of soil organic matter (Schaphoff et al., 2013).

PFT	$\tau 10_{\mathrm{leaf,litter}}$ (a^{-1})	$\tau 10_{\mathrm{wood,litter}}$ (a^{-1})	$Q10_{\mathrm{wood,litter}}$ (-)	k_{soc} (-)
TrBE	0.93	0.039	2.75	0.38009
TrBR	1.17	0.039	2.75	0.51395
TeNE	0.70	0.041	1.97	0.32198
TeBE	0.86	0.104	1.37	0.43740
TeBS	0.95	0.104	1.37	0.28880
BoNE	0.76	0.041	1.97	0.28670
BoBS	0.94	0.104	1.37	0.28670
BoNS	0.76	0.041	1.97	0.28670
TrH	0.97	-	-	0.46513
TeH	1.20	-	-	0.38184
PoH	1.20	-	-	0.38184
BTrT	0.93	0.039	2.75	0.38009
BTeT	0.95	0.104	1.37	0.28880
BGrC4	0.97	-	-	0.46513
All crops	0.97	-	-	0.40428

Table S8. PFT-specific parameters.

PFT	β_{root}	g_{min} (mm s^{-1})	α_{leaf} (a)	τ_{leaf} (a)	τ_{root} (a)	τ_{sapwood} (a)	r_{PFT} gC gN^{-1} day^{-1}	$\mathrm{lr}_{\mathrm{max}}$
TrBE	0.962	0.5	1.60	2.0	2.0	20.0	0.2	1.0
TrBR	0.961	0.5	0.50	1.0	1.0	20.0	0.2	1.0
TeNE	0.976	0.5	4.00	4.0	4.0	20.0	1.2	1.0
TeBE	0.964	0.5	1.60	1.0	1.0	20.0	1.2	1.0
TeBS	0.966	0.5	0.45	1.0	1.0	20.0	1.2	1.0
BoNE	0.943	0.3	4.00	4.0	4.0	20.0	1.2	1.0
BoBS	0.943	0.5	0.50	1.0	1.0	20.0	1.2	1.0
BoNS	0.943	0.5	0.65	1.0	1.0	20.0	1.2	1.0
TrH	0.972	0.5	0.40	1.0	2.0	-	0.2	0.60
TeH	0.943	0.5	0.35	1.0	2.0	-	1.2	0.60
PoH	0.943	0.5	0.35	1.0	2.0	-	1.2	0.60

β_{root} is the root distribution slope parameter for water availability, g_{min} is the minimum canopy conductance, α_{leaf} is the leaf longevity, $\tau_{\mathrm{leaf,root,sapwood}}$ is the compartment specific turnover times, r_{PFT} is the respiration coefficient for maintenance respiration of sapwood and root, $\mathrm{lr}_{\mathrm{max}}$ is the maximum leaf-to-root mass ratio

Table S9. PFT-specific parameters for the SPITFIRE module.

PFT	α_p	ρ_b	m_e	Φ_w	scorch height	crown length	r_{CK}	p
TrBE	0.0000334	25	0.3	0.4	0.1487	0.3334	1.0	3.00
TrBR	0.0000334	13	0.3	0.4	0.0610	0.1000	0.05	3.00
TeNE	0.0000667	25	0.3	0.4	0.1000	0.3334	1.00	3.75
TeBE	0.0000334	22	0.3	0.4	0.3710	0.3334	0.95	3.00
TeBS	0.0000667	22	0.3	0.4	0.0940	0.3334	1.0	3.00
BoNE	0.0000667	25	0.3	0.4	0.1100	0.3334	1.0	3.00
BoBS	0.0000667	22	0.3	0.4	0.0940	0.3334	1.0	3.00
BoNS	0.0000667	22	0.3	0.4	0.0940	0.3334	1.0	3.00
TrH	0.0000667	2	0.3	0.6	-	-	-	-
TeH	0.0000667	4	0.3	0.6	-	-	-	-
PoH	0.0000667	4	0.3	0.6	-	-	-	-

α_p defines the slope of the probability risk function, ρ_b is the fuel bulk density, m_e is the moisture of extinction,Φ_w is the windspeed dampening , r_{CK} is the resistance factor, p is the crown damage parameter

Table S10. Parameters for annual CFTs for the computation of variety and sowing day parameters.

CFT	representative crop	crops represented	$\mathrm{PHU}_{w_{\mathrm{low}}}$	$\mathrm{PHU}_{w_{\mathrm{high}}}$	$\mathrm{PHU}_{s_{\mathrm{low}}}$	$\mathrm{PHU}_{s_{\mathrm{high}}}$	$T_{\mathrm{base_{low}}}$	$T_{\mathrm{base_{high}}}$	pf	T_{fall}	T_{spring}	T_{vern}
temperate cereals	wheat	wheat, rye, barley	1700	2876.9	1000	2648.4	0.0	0.0	200	12	5	12
rice	rice	paddy rice	NA	NA	1600	1800	10	10	167	NA	18	NA
maize	maize	maize for food	NA	NA	1600	1600	5	15	167	NA	14	NA
tropical cereals	millet	millet, sorghum	NA	NA	1500	1500	10	10	167	NA	12	NA
pulses	field pea	pulses	NA	NA	2000	2000	1.0	1.0	167	NA	10	NA
temperate roots	sugar beet	sugar beet	NA	NA	2700	2700	3.0	3.0	167	NA	8	NA
tropical roots	cassava	cassava	NA	NA	2000	2000	15	15	167	NA	22	NA
sunflower	sunflower	sunflower	NA	NA	1000	1600	6.0	6.0	167	NA	13	NA
soybean	soybean	soybean	NA	NA	1000	1000	10	10	167	NA	13	NA
groundnuts	groundnuts	groundnuts	NA	NA	1500	1500	14	14	167	NA	15	NA
rapeseed	rapeseed	rapeseed	2100	3279.7	1000	2648.4	0.0	0.0	200	17	5	12
sugarcane	sugarcane	sugarcane	NA	NA	2000	4000	11	15	167	NA	14	NA

Table S11. Parameters for annual CFTs for the computation of LAI development and biomass allocation.

CFT	β_{root}	fPHU_c	$\mathrm{fLAI}_{\mathrm{max}_c}$	fPHU_k	$\mathrm{fLAI}_{\mathrm{max}_k}$	$\mathrm{fPHU}_{\mathrm{sen}}$	ssn	$\mathrm{fLAI}_{\mathrm{max}_h}$	α_{leaf}	$\mathrm{HI}_{\mathrm{opt}}$
temperate cereals	0.9690	0.05	0.05	0.45	0.95	0.7	2.0	0.0	0.5	0.5
rice	0.9690	0.1	0.05	0.5	0.95	0.8	2.0	0.0	0.5	0.5
maize	0.9690	0.1	0.05	0.5	0.95	0.75	2.0	0.0	0.5	0.5
tropical cereals	0.9690	0.15	0.01	0.5	0.95	0.85	2.0	0.0	0.5	0.25
pulses	0.9690	0.15	0.01	0.5	0.95	0.90	2.0	0.0	0.5	0.45
temperate roots	0.9690	0.15	0.05	0.5	0.95	0.75	0.5	0.75	0.5	3.5
tropical roots	0.9690	0.15	0.05	0.5	0.95	0.75	0.5	0.75	0.5	2.0
sunflower	0.9690	0.15	0.01	0.5	0.95	0.7	2.0	0.0	0.5	0.4
soybean	0.9690	0.15	0.05	0.5	0.95	0.7	0.5	0.0	0.5	0.4
groundnuts	0.9690	0.15	0.01	0.5	0.95	0.75	0.5	0.0	0.5	0.4
rapeseed	0.9690	0.05	0.01	0.5	0.95	0.85	2.0	0.0	0.5	0.3
sugarcane	0.9690	0.01	0.01	0.4	0.95	0.95	2.0	0.5	0.5	0.8

Table S12. Model parameters describing biomass plantation management.

BFT	Corresponding biomass crop	Harvest interval	Plant density (ha^{-1})
BTrT	Poplar, Willow	8 years	8000
BTeT	Eucalyptus	8 years	5000
BGrC4	Miscanthus, Switchgrass	(Multiple) annual harvest	n.a.

Table S13. Overview of BFT parameter values and constants in model equations.

Parameter	Description	BTrT	BTeT	BGrC4
g_{min}	Minimum canopy conductance	0.2	0.2	0.5
$\mathrm{LAI}_{\mathrm{sapl}}$	Leaf area index of saplings (-)	1.6	1.6	0.001
α_a	fraction of PAR absorbed at ecosystem level, relative to leaf level (-)	0.8	0.8	0.8
$T_{\mathrm{lim,CO2}}$	lower and upper temperature limit for CO_2 (°C)	24,55	-4.0, 38.0	4, 55
$T_{\mathrm{lim,opt,photo}}$	lower and upper limit of temperature optimum for photosynthesis (°C)	25, 38	15, 30	15, 45
$T_{\mathrm{lim,cold,month}}$	lower and upper coldest monthly mean temperature (°C)	7, -	-30, 8	-40, -
$\tau_{\mathrm{leaf,root,sapwood}}$	Turnover leaf, root, sapwood	2, 2, 10	1, 1, 10	1,2,-
$\mathrm{CA}_{\mathrm{max}}$	Tree maximum crown area (m^2)	2	1.5	-
$C_{\mathrm{sapwood,sapling}}$	sapling carbon (gC m^{-2})	2.2	2.5	-
k_{allom1}	Allometry parameter 1	110	110	-
k_{allom2}	Allometry parameter 2	35	35	-
k_{allom3}	Allometry parameter 3	0.75	0.75	-
k_{est}	Saplings per m^2	0.5	0.8	-

Table S14. Parametrisation of irrigation systems in LPJmL4.

Irrigation system	Distribution uniformity scalar	Conveyance efficiency[1]	Soil evaporation	Inter-ception	Runoff	Irrigation threshold[2]	Minimal irrig. amount
Surface	1.15	open canal: sand 0.7, loam 0.75, clay 0.8	unrestricted	no	surface, lateral, percolation	C_4: 0.7 C_3 (Pr <900): 0.8 C_3 (Pr$\geq$ 900): 0.9 Rice: 1.0	1 mm
Sprinkler	0.55	pipe: 0.95		yes	lateral, percolation		
Drip	0.05		soil evap. of irr. water reduced by 60%	no	none, only indirect precip. leaching		none

[1] open canal conveyance efficiency depends on soil hydraulic conductivity (K_s): $K_s > 20$: sand, $10 \leq K_s \leq 20$: loam, $K_s < 10$: clay; 50% of conveyance losses are assumed to evaporate, for loam and clay (higher K_s) and open canal conveyance the fraction is 60% and 75%, resp. [2] depending on crop type, see Jägermeyr et al. (2015) for details.

Table S15: Equation table describing the different processes represented in the LPJmL4 model.

Parameter/Variable	abbreviation	unit	Equation
		Energy balance	
Photosynthetic active radiation	PAR	mol m^{-2} day^{-1}	$\mathrm{PAR} = 0.5 \cdot c_q \cdot R_{s_\mathrm{day}}$
conversion factor from J to mol for solar radiation at 550 nm	c_q		$c_q = 4.6 \cdot 10^{-6}$
daily incoming solar irradiance	R_{s_day}	J m^{-2} day^{-1}	$R_{s_\mathrm{day}} = (c + d \cdot \mathrm{ni}) \cdot Q_0 \cdot (\sin(\mathrm{lat}) \cdot \sin(\delta) \cdot h_{1/2} + \cos(\mathrm{lat}) \cdot \cos(\delta) \cdot h_{1/2})$
potential evapotranspiration	PET	mm day^{-1}	$\mathrm{PET} = \mathrm{PT} \cdot E_\mathrm{eq}$
equilibrium evapotranspiration	E_eq	mm day^{-1}	$E_\mathrm{eq} = \frac{s}{s+\gamma} \cdot \frac{R_{n_\mathrm{day}}}{\lambda}$
daily surface net radiation	R_{n_day}	J m^{-2} day^{-1}	
latent heat of vaporization	λ	J kg^{-1}	$\lambda = 2.495 \times 10^6 + 2380 \cdot T_\mathrm{air}$
slope of the saturation vapour pressure curve	s	Pa K^{-1}	$s = 2.502 \times 10^6 \cdot \exp[17.269 \cdot T_\mathrm{air}/(237.3 + (237.3 + T_\mathrm{air}))]/(237.3 + T_\mathrm{air})^2$
psychrometric constant	γ	Pa K^{-1}	$\gamma = 65.05 + 0.064 \cdot T_\mathrm{air}$
Priestley-Taylor coefficient	PT		
net surface radiation	R_n	W m^{-2}	
incoming solar irradiance (downward) at the surface	R_s	W m^{-2}	$R_s = (c + d \cdot \mathrm{ni}) \cdot Q_0 \cdot \cos(z)$ or as input
outgoing (upward positive) net long-wave radiation flux at the surface	R_l	W m^{-2}	$R_l = (b + (1-b) \cdot \mathrm{ni}) \cdot (A - T_\mathrm{air})$ or as input
albedo	β		$\beta = \sum_{\mathrm{PFT}=1}^{n_\mathrm{PFT}} \beta_\mathrm{PFT} \cdot \mathrm{FPC}_\mathrm{PFT} + F_\mathrm{bare} \cdot (F_\mathrm{snow} \cdot \beta_\mathrm{snow} + (1 - F_\mathrm{snow}) \cdot \beta_\mathrm{soil})$
albedo bare soil	β_soil		
albedo snow	β_snow		
plant compartments specific albedo	β_PFT		
coverage of bare soil	F_bare		
coverage of snow	F_snow		
empirical constant	b		see Prentice et al. (1993)
empirical constant	A		see Prentice et al. (1993)
mean daily air temperature	T_air	°C	
net outgoing daytime long-wave flux	$R_{l_{n_\mathrm{day}}}$	J m^{-2} day^{-1}	$R_{l_\mathrm{day}} = R_l \cdot \mathrm{daylength} \cdot 3600$
angular distance between the sun's rays and the local vertical	z		
proportion of bright sky	ni		$\mathrm{ni} = 1 - \mathrm{cloudiness}$
empirical constant	c		see Prentice et al. (1993)

Parameter/Variable	abbreviation	unit	Equation
empirical constant	d		see Prentice et al. (1993)
solar constant	Q_0	W m^{-2}	$Q_0 = Q_{00} \cdot (1 + 2 \cdot 0.01675 \cdot \cos(2 \cdot \pi \cdot i/365))$
solar zenith angle	z		$\cos(z) = \sin(\mathrm{lat}) \cdot \sin(\delta) + \cos(\mathrm{lat}) \cdot \cos(\delta) \cdot \cos(h)$
latitude	lat	radians	
hour angle	h		
solar declination	δ	radians	$\delta = -23.4 \cdot \pi/180 \cdot \cos(2 \cdot \pi \cdot (i+10)/365)$
half-day length	$h_{1/2}$	angular units	$h_{1/2} = \arccos(-(\sin(\mathrm{lat}) \cdot \sin(\delta))/(\cos(\mathrm{lat}) \cdot \cos(\delta)))$
duration of sunshine of a single day	daylength	hours	$\mathrm{daylength} = 24 \cdot \frac{h_{1/2}}{\pi}$
Soil temperatures	T_{soil}	°C	$\frac{\partial T_{\mathrm{soil}}}{\partial t} = \alpha \cdot \frac{\partial^2 T_{soil}}{\partial z^2}$
thermal diffusivity	$\alpha = \lambda/c$	m^2 s^{-1}	
thermal conductivity	λ	W m^{-1} K^{-1}	
soil layer	l		
time step	t		
stability criterion	r		$r = \frac{\alpha \Delta t}{(\Delta z)^2}$
Heat capacity	c	J K^{-1} m^{-3}	$c = c_{\mathrm{min}} \cdot m_{\mathrm{min}} + c_{\mathrm{water}} \cdot m_{\mathrm{water}} + c_{\mathrm{ice}} \cdot m_{\mathrm{ice}}$
soil minerals	c_{min}		
soil water content	c_{water}		
soil ice content	c_{ice}		
corresponding shares of $c_{\mathrm{min}}, c_{\mathrm{water}}, c_{\mathrm{ice}}$	m	m^3	
		Plant physiology	
absorbed photosynthetically active radiation	APAR	mol m^{-2} day^{-1}	$\mathrm{APAR_{PFT}} = \mathrm{PAR} \cdot \mathrm{FAPAR_{PFT}} \cdot \alpha_{\mathrm{aPFT}}$
fractional absorbed photosynthetically active radiation	$\mathrm{FAPAR_{PFT}}$		$\mathrm{FAPAR_{PFT}} = \mathrm{FPC_{PFT}} \cdot \Big((\mathrm{phen_{PFT}} - \mathrm{F_{SnowGC}}) \cdot (1 - \beta_{\mathrm{leaf,PFT}}) - \big((1 - \mathrm{phen_{PFT}}) \cdot c_{\mathrm{fstem}} \cdot \beta_{\mathrm{stem,PFT}}\big)\Big)$
scaling factor to scale leaf-level photosynthesis in LPJmL4 to biome level	α_{aPFT}		
daily phenological status	$\mathrm{phen_{PFT}}$		
fraction of snow in the green canopy	F_{SnowGC}		
foliage projective cover of the respective PFT	$\mathrm{FPC_{PFT}}$		$\mathrm{FPC_{PFT}} = \mathrm{CA_{ind}} \cdot P \cdot \mathrm{FPC_{ind}}$
masking of the ground by stems and branches without leaves	c_{fstem}		
gross photosynthesis rate	A_{gd}	gC m^{-2} day^{-1}	$A_{\mathrm{gd}} = \left(J_E + J_C - \sqrt{(J_E + J_C)^2 - 4 \cdot \theta \cdot J_E \cdot J_C}\right)/(2 \cdot \theta) \cdot \mathrm{daylength}$
light-limited photosynthesis rate	J_E	mol C m^{-2} hour^{-1}	$J_E = C_1 \cdot \frac{\mathrm{APAR}}{\mathrm{daylength}}$
for C_3-Photosynthesis			$C_1 = \alpha_{C_3} \cdot T_{\mathrm{stress}} \cdot \left(\frac{p_i - \Gamma_*}{p_i + 2 \cdot \Gamma_*}\right)$

Parameter/Variable	abbreviation	unit	Equation
for C_4-Photosynthesis			$C_1 = \alpha_{C_4} \cdot T_{\text{stress}} \cdot \left(\frac{\lambda}{\lambda_{\max_{C4}}}\right)$
internal partial pressure of CO_2	p_i	Pa	$p_i = \lambda \cdot p_a$
ambient partial pressure of CO_2	p_a	Pa	
parameter describing the ratio of the intercellular to the ambient CO_2 concentration	λ		
PFT-specific temperature inhibition function	T_{stress}		
intrinsic quantum efficiencies for CO_2 uptake in C_3 plants	α_{C_3}		
intrinsic quantum efficiencies for CO_2 uptake in C_4 plants	α_{C_4}		
CO_2 compensation point	Γ_*		$\Gamma_* = \frac{[O_2]}{2 \cdot \tau}$
specificity factor	τ		$\tau = \frac{V_c \cdot K_C}{V_m \cdot K_O}$
Michaelis-Menten constant of CO_2	K_C		
Michaelis-Menten constant of O_2	K_O		
partial pressure of O_2	O_2	Pa	
Rubisco-limited photosynthesis rate	J_C	mol C m^{-2} $hour^{-1}$	$J_C = C_2 \cdot V_m$
maximum Rubisco capacity	V_m	gC m^{-2} day $^{-1}$	$V_m = \frac{1}{b} \cdot \frac{C_1}{C_2}((2 \cdot \theta - 1) \cdot s - (2 \cdot \theta \cdot s - C_2) \cdot \sigma) \cdot \text{APAR}$
	σ		$\sigma = \sqrt{1 - \frac{C_2 - 2}{C_2 - \theta s}}$
	s		$s = 24/\text{daylength} \cdot b$
	C_2		$C_2 = \frac{p_i - \Gamma_*}{p_i + K_C\left(1 + \frac{[O_2]}{K_O}\right)}$
leaf respiration	R_{leaf}	gC m^{-2} day $^{-1}$	$R_{\text{leaf}} = V_m \cdot b$
daily net photosynthesis	A_{nd}	gC m^{-2} day $^{-1}$	
dark respiration	R_d	gC m^{-2} day $^{-1}$	$R_d = (1 - \text{daylength}/24) \cdot R_{\text{leaf}}$
daily net daytime photosynthesis	A_{dt}	gC m^{-2} day $^{-1}$	$A_{\text{dt}} = A_{\text{nd}} + R_d$
canopy conductance	g_c	mm s^{-1}	$g_c = g_{\min} + \frac{1.6 A_{dt}}{p_a(1-\lambda)}$
PFT-specific minimum canopy conductance	$g_{\min}$	mm s^{-1}	
daily phenology status	phen_{PFT}		$\text{phen}_{\text{PFT}} = f_{\text{cold}} \cdot f_{\text{light}} \cdot f_{\text{water}} \cdot f_{\text{heat}}$
limited by cold temperatures	f_{cold}		
relation to light	f_{light}		
relation to water availability	f_{water}		
limited by heat stress	f_{heat}		
inflection point of the respective logistic function	b_x		
slope of the respective logistic function	sl_x		
change rate parameter	τ_x		
CN ratio of above-ground tissue	$\text{CN}_{\text{sapwood}}$		
CN ratio of below-ground tissue	CN_{root}		
Temperature	T (T_{air}, T_{soil})	$^{\circ}C$	

Parameter/Variable	abbreviation	unit	Equation
phenology	$\mathrm{phen}_{\mathrm{PFT}}$		
autotrophic respiration aboveground tissue	R_{sapwood}	gC m^{-2} day^{-1}	$R_{\mathrm{sapwood}} = P \cdot r_{\mathrm{PFT}} \cdot k \cdot \frac{C_{\mathrm{sapwood,ind}}}{CN_{\mathrm{sapwood}}} \cdot g(T_{\mathrm{air}})$
autotrophic respiration belowground tissue	R_{root}	gC m^{-2} day^{-1}	$R_{\mathrm{root}} = P \cdot r_{\mathrm{PFT}} \cdot k \cdot \frac{C_{\mathrm{root,ind}}}{CN_{\mathrm{root}}} \cdot g(T_{\mathrm{soil}}) \cdot \mathrm{phen}_{\mathrm{PFT}}$
respiration rate	r_{PFT}	gC gN^{-1} day^{-1}	
temperature function	$g(T)$		$g(T) = \exp\left[308.56 \cdot \left(\frac{1}{56.02} - \frac{1}{(T+46.02)}\right)\right]$
leaf respiration	R_{leaf}		$R_{\mathrm{leaf}} = V_m \cdot b$
static parameter	b		
daily net primary production	NPP	gC m^{-2} day^{-1}	$\mathrm{NPP} = 0.75 \cdot (\mathrm{GPP} - R_{\mathrm{leaf}} - R_{\mathrm{sapwood}} - R_{\mathrm{root}})$

Plant functional types (PFT)

leaf mass	$C_{\mathrm{leaf,ind}}$	gC· ind^{-1}	
fine root mass	$C_{\mathrm{root,ind}}$	gC· ind^{-1}	
sapwood mass	$C_{\mathrm{sapwood,ind}}$	gC· ind^{-1}	
heartwood mass	$C_{\mathrm{heartwood,ind}}$	gC· ind^{-1}	
average individual leaf area	$\mathrm{LA}_{\mathrm{ind}}$	m^2· ind^{-1}	$\mathrm{LA}_{\mathrm{ind}} = k_{\mathrm{la:sa}} \cdot \mathrm{SA}_{\mathrm{ind}}$
ratio of leaf to sapwood area	$k_{\mathrm{la:sa}}$		
sapwood cross-sectional area	$\mathrm{SA}_{\mathrm{ind}}$		
grass leaf biomass	C_{leaf}	gC m^{-2}	$C_{\mathrm{leaf}} = \mathrm{lr}_{\mathrm{max}} \cdot \omega \cdot C_{\mathrm{roots}}$
leaf-to-root mass ratio	lr		$\mathrm{lr} = \mathrm{lr}_p \cdot W_{\mathrm{supply}}/W_{\mathrm{demand}}$
maximum leaf-to-root mass ratio	$\mathrm{lr}_{\mathrm{max}}$		
tree height	H	m	$H = k_{\mathrm{allom2}} \cdot D^{k_{\mathrm{allom3}}}$
stem diameter	D	m	
crown area	$\mathrm{CA}_{\mathrm{ind}}$	m^2· ind^{-1}	$\mathrm{CA}_{\mathrm{ind}} = k_{\mathrm{allom1}} \cdot D^{k_{\mathrm{rp}}}$
constant wood density	WD	gC m^{-2}	$H = \frac{C_{\mathrm{sapwood,ind}} \cdot k_{\mathrm{la:sa}}}{\mathrm{WD} \cdot C_{\mathrm{leaf,ind}} \cdot \mathrm{SLA}}$
individual leaf area index	$\mathrm{LAI}_{\mathrm{ind}}$		$\mathrm{LAI}_{\mathrm{ind}} = \frac{C_{\mathrm{leaf,ind}} \cdot \mathrm{SLA}}{\mathrm{CA}_{\mathrm{ind}}}$
specific leaf area	SLA	m^2 gC^{-1}	$\mathrm{SLA} = \frac{2 \times 10^{-4}}{DM_C} \cdot 10^{(\beta_0 - \beta_1 \cdot \log(\alpha_{\mathrm{leaf}})/\log(10)}$
leaf longevity	α_{leaf}	months	
parameter for SLA calculation	β_0		Kattge et al. (2011)
parameter for SLA calculation	β_1		Kattge et al. (2011)
dry matter carbon content of leaves	DM_C		Kattge et al. (2011)
foliar projective cover	$\mathrm{FPC}_{\mathrm{ind}}$		$\mathrm{FPC}_{\mathrm{ind}} = 1 - \exp(-k \cdot \mathrm{LAI}_{\mathrm{ind}})$
mean number of individuals per unit area	P	ind m^{-2}	
establishment rate	k_{est}	saplings m^{-2} a^{-1}	
background mortality rate	$\mathrm{mort}_{\mathrm{greff}}$	ind m^{-2} a^{-1}	$\mathrm{mort}_{\mathrm{greff}} = P \cdot \frac{k_{\mathrm{mort1}}}{1 + k_{\mathrm{mort2}} \cdot \mathrm{greff}}$
yearly growth efficiency	greff		
asymptotic maximum mortality rate	k_{mort1}		

Parameter/Variable	abbreviation	unit	Equation
parameter governing the slope of the relationship between mortality and growth efficiency	k_{mort2}		
heat stress	$\mathrm{mort}_{\mathrm{heat}}$	ind $\mathrm{m}^{-2}\,\mathrm{a}^{-1}$	$\mathrm{mort}_{\mathrm{heat}} = P \cdot \frac{\mathrm{gdd}_{\mathrm{tw}}}{\mathrm{tw}_{\mathrm{PFT}}}$
parameter value of the heat damage function	$\mathrm{tw}_{\mathrm{PFT}}$		
temperatures above threshold (accumulated)	$\mathrm{gdd}_{\mathrm{tw}}$	°C	
Nesterov index	$\mathrm{NI}(N_d)$		$\mathrm{NI}(N_d) = \sum_{if\,\mathrm{P}(d)\leq 3\mathrm{mm}}^{N_d} T_{\mathrm{max}}(d) \cdot \left(T_{\mathrm{max}}(d) - T_{\mathrm{dew}}(d)\right)$
daily maximum temperature	T_{max}	°C	
dew-point temperature	T_{dew}	°C	
positive temperature day	d		
probability of fire spread	P_{spread}		$P_{\mathrm{spread}} = \begin{cases} 1 - \frac{\omega_0}{m_e}, & \omega_0 \leq m_e \\ 0, & \omega_0 > m_e \end{cases}$
litter moisture	ω_0		
moisture of extinction	m_e		
fire danger index	FDI		$\mathrm{FDI} = \max\left\{0, 1 - \frac{1}{m_e} \cdot \exp\left(-\mathrm{NI} \cdot \sum_{p=1}^{n} \frac{\alpha_p}{n}\right)\right\}$
slope of the probability risk function	α_p		
Human-caused ignitions	$n_{h,\mathrm{ig}}$		$n_{h,\mathrm{ig}} = P_D \cdot k(P_D) \cdot a(N_D)/100$
population density	P_D	ind km^{-2}	$k(P_D) = 30.0 \cdot \exp(-0.5 \cdot \sqrt{P_D})$
propensity of people to produce ignition events	$a(N_D)$	ignitions individual^{-1} d^{-1}	$a(N_D) = \frac{N_{h,\mathrm{obs}}}{t_{\mathrm{obs}} \cdot \mathrm{LFS} \cdot \overline{P_D}}$
average number of human-caused fires	$N_{h,\mathrm{obs}}$		
observation years	t_{obs}		
grid cell area	A	m^2	$A_b = \min(E(n_{\mathrm{ig}}) \cdot \mathrm{FDI} \cdot A_f, A)$
mean fire area	a_f	ha	$\overline{a_f} = \frac{\frac{\pi}{4 \cdot L_B} \cdot D_T^2}{10000}$
independent estimates of the numbers of lightning	$n_{l,\mathrm{ig}}$		
human-caused ignition events	$n_{h,\mathrm{ig}}$		
forward rate of spread	$\mathrm{ROS}_{f,\mathrm{surface}}$	m min^{-1}	$\mathrm{ROS}_{f,\mathrm{surface}} = \frac{I_R \cdot \zeta \cdot (1+\Phi_w)}{\rho_b \cdot \epsilon \cdot Q_{\mathrm{ig}}}$
reaction intensity	I_R	kJ m^{-2} min^{-1}	
propagating flux ratio	ζ		
multiplier that accounts for the effect of wind	Φ_w		
fuel bulk density	ρ_b	kg m^{-3}	
effective heating number	ϵ		
heat of pre-ignition	Q_{ig}	kJ kg^{-1}	
fire duration	t_{fire}	min	$t_{\mathrm{fire}} = \frac{241}{1+240 \cdot \exp(-11.06 \cdot \mathrm{FDI})}$
length to breadth ratio of elliptical fire	L_B		
length of major axis	D_T	m	$D_T = \mathrm{ROS}_{f,\mathrm{surface}} \cdot t_{\mathrm{fire}} + \mathrm{ROS}_{b,\mathrm{surface}} \cdot t_{\mathrm{fire}}$
surface as the backward rate of spread	ROS_b		
crown damage	CK		$P_m(\mathrm{CK}) = r_{\mathrm{CK}} \cdot \mathrm{CK}^p$

Parameter/Variable	abbreviation	unit	Equation
resistance factor	r_{CK}	0-1	
Crop functional types (CFT)			
phenological heat unit	PHU		$\mathrm{PHU} = -0.1081 \cdot (\mathrm{sdate} - \mathrm{keyday})^2 + 3.1633 \cdot (\mathrm{sdate} - \mathrm{keyday}) + \mathrm{PHU}_{w_{\mathrm{high}}}$
harvest indices	$\mathrm{HI}_{\mathrm{opt}}$		
heat units	HU		
heat units accumulated	$\mathrm{HU}_{\mathrm{sum}}$		$\mathrm{HU}_{\mathrm{sum}} = \sum_{t'=\mathrm{sdate}}^{t} \mathrm{HU}_{t'} \cdot v_{\mathrm{rf}} \cdot p_{\mathrm{rf}}$
phenological development stage	fPHU		$\mathrm{fPHU} = \mathrm{HU}_{\mathrm{sum}}/\mathrm{PHU}$
reduction factor for vernalization	v_{rf}		$v_{\mathrm{rf}} = (\mathrm{vdsum} - 10.0)/(\mathrm{PVD} - 10.0)$
reduction factor for photoperiod	p_{rf}		$p_{\mathrm{rf}} = (1 - p_{\mathrm{sens}}) \cdot \min(1, \max(0, (\mathrm{daylength} - p_b)/(p_s - p_b))) + p_{\mathrm{sens}}$
day of solstice	keyday		
minimum base temperature for the accumulation of heat unit	$T_{\mathrm{base}_{\mathrm{low}}}$		
20-year moving average annual temperature	atemp_{20}		
CFT-specific scaling factor	$\mathrm{pf}_{\mathrm{CFT}}$		
Vernalization requirements	PVD		$\mathrm{PVD} = \mathrm{vern}_{\mathrm{date20}} - \mathrm{sdate} - \mathrm{pPVD}_{\mathrm{CFT}}, \quad 0 \leq \mathrm{PVD} \leq 60$
CFT-specific vernalization factor	$\mathrm{pPVD}_{\mathrm{CFT}}$		
julian day of the year of sowing	sdate		
multi-annual average of the first day of the year when temperatures rise above a CFT-specific vernalization threshold	$\mathrm{vern}_{\mathrm{date20}}$		
effective number of vernalizing days	vdsum		
parametrized sensitivity to photoperiod	p_{sens}		
duration of daylight (sunrise to sunset)	daylength	hours	
base photoperiod	p_b	hours	
aturation photoperiod	p_s	hours	
maximum leaf area index	$\mathrm{LAI}_{\mathrm{max}}$		
fraction of total biomass that is allocated to the roots	f_{root}		$f_{\mathrm{root}} = \frac{0.4 - (0.3 \cdot \mathrm{fPHU}) \cdot \mathrm{wdf}}{\mathrm{wdf} + \exp(6.13 - 0.0883 \cdot \mathrm{wdf})}$
ratio between accumulated daily transpiration and accumulated daily water demand	wdf		
onset of senescence	ssn		
turning points in the phenological development	fPHU_c, fPHU_k		

Parameter/Variable	abbreviation	unit	Equation
corresponding fraction of the maximum green LAI	$\mathrm{fLAI}_{\mathrm{max}_c}$, $\mathrm{fLAI}_{\mathrm{max}_k}$		$\mathrm{fLAI}_{\mathrm{max}} = \frac{\mathrm{fPHU}}{\mathrm{fPHU}+c\cdot(\frac{c}{k})^{\frac{\mathrm{fPHU}_c-\mathrm{fPHU}}{\mathrm{fPHU}_k-\mathrm{fPHU}_c}}}$
onset of senescence as point in the phenological development	$\mathrm{fPHU}_{\mathrm{sen}}$		
daily increment	$\mathrm{LAI}_{\mathrm{inc},t}$		$\mathrm{LAI}_{\mathrm{inc},t} = (\mathrm{fLAI}_{\mathrm{max}_t} - \mathrm{fLAI}_{\mathrm{max}_{t-1}}) \cdot \mathrm{LAI}_{\mathrm{max}}$
maximum green LAI	$\mathrm{fLAI}_{\mathrm{max}}$		
LAI	LAI		$\mathrm{LAI}_t = \sum_{t'=\mathrm{sdate}}^{t} \mathrm{LAI}_{\mathrm{inc}_{t'}} \cdot \omega$
harvest index	HI		$\mathrm{HI} = \begin{cases} \mathrm{fHI}_{\mathrm{opt}} \cdot \mathrm{HI}_{\mathrm{opt}}, & \text{if } \mathrm{HI}_{\mathrm{opt}} \geq 1 \\ \mathrm{fHI}_{\mathrm{opt}} \cdot (\mathrm{HI}_{\mathrm{opt}} - 1.0) + 1.0, & \text{otherwise} \end{cases}$
	$\mathrm{fHI}_{\mathrm{opt}}$		$\mathrm{fHI}_{\mathrm{opt}} = 100 \cdot \mathrm{fPHU}/(100 \cdot \mathrm{fPHU} + \exp(11.1 - 10.0 \cdot \mathrm{fPHU}))$
storage organ	C_{so}	gC m^{-2}	$C_{\mathrm{so}} = \mathrm{HI} \cdot (C_{\mathrm{leaf}} + C_{\mathrm{so}} + C_{\mathrm{pool}})$
Excess biomass	C_{pool}	gC m^{-2}	
		Soil and litter carbon pools	
heterotrophic respiration	R_h	gC m^{-2} day^{-1}	$R_h = R_{h,\mathrm{litter}} + R_{h,\mathrm{fastSoil}} + R_{h,\mathrm{slowSoil}}$
carbon pool size of soil or litter per layer	C_l	gC m^{-2} $layer^{-1}$	$\frac{dC_{(l)}}{dt} = -k_{(l)} \cdot C_{(l)}$
decomposition rates for litter	k	a^{-1} $layer^{-1}$	$k_{(l,p)} = \frac{1}{\tau_{10_{(p)}}} \cdot g(T_{\mathrm{soil}}) \cdot f(\theta)$
mean residence time	τ_{10}	a	
soil volume fraction of the layer	θ		
fraction of soil organic carbon per layer	Cf_l		$\mathrm{Cf}_{(l)} = 10^{k_{\mathrm{soc}} \cdot \log_{10}(d_{(l)})}$
relative share of the layer l	$d_{(l)}$		
soil layer depth	k_{soc}	mm	
total amount of soil carbon	$C_{s_{\mathrm{total}}}$	gC	$C_{(l)} = \sum_{\mathrm{PFT}=1}^{n_{PFT}} d_{(l)}^{k_{\mathrm{soc}_{\mathrm{PFT}}}} \cdot C_{s_{\mathrm{total}}}$
mean annual decomposition rate	k_{mean}	gC a^{-1}	
mean decomposition rate for each PFT	$k_{\mathrm{mean}_{\mathrm{PFT}}}$		$k_{\mathrm{mean}_{\mathrm{PFT}}} = \sum_{l=1}^{n_{\mathrm{soil}}} (k_{\mathrm{mean}_{(l)}} \cdot \mathrm{Cf}_{(l,\mathrm{PFT})})$
annual carbon shift rates	C_{shift}	a^{-1}	$C_{\mathrm{shift}_{(l,\mathrm{PFT})}} = \frac{Cf_{(l,\mathrm{PFT})} \cdot k_{\mathrm{mean}_{(l)}}}{k_{\mathrm{mean}_{\mathrm{PFT}}}}$
infiltration rate of rain water into the soil	infil	mm	$\mathrm{infil} = \mathrm{Pr} \cdot \sqrt{1 - \frac{\mathrm{SW}_{(0)} - \mathrm{WPW}_{(0)}}{W_{\mathrm{sat}_{(0)}} - \mathrm{WPW}_{(0)}}}$
		Water balance	
soil water content at saturation	W_{sat}	mm	
soil water content at wilting point	W_{pwp}	mm	
total actual soil water content	SW	mm	

Parameter/Variable	abbreviation	unit	Equation
daily precipitation	Pr	mm	routed in 4 mm portion in the infiltration equation
soil water content between saturation and field capacity	FW	mm	
soil layer	l		
travel time through the soil layer	TT	hours	$\mathrm{TT}_{(l)} = \dfrac{\mathrm{FW}_{(l)}}{\mathrm{HC}_{(l)}}$
hydraulic conductivity	HC	mm h^{-1}	$\mathrm{HC}_{(l)} = K_{s_{(l)}} \cdot \left(\frac{\mathrm{SW}_{(l)}}{W_{\mathrm{sat}_{(l)}}}\right)^{\beta_{(l)}}$
saturated conductivity	K_s	mm h^{-1}	
percolation	perc	mm day^{-1}	$\mathrm{perc}_{(l)} = \mathrm{FW}_{(t,l)} \cdot \left[1 - \exp\left(\frac{-\Delta t}{\mathrm{TT}_{(l)}}\right)\right]$
Interception	I	mm day^{-1}	$I = \sum_{\mathrm{PFT}=1}^{n_{\mathrm{PFT}}} I_{\mathrm{PFT}} \cdot \mathrm{LAI}_{\mathrm{PFT}} \cdot \mathrm{Pr}$
PFT-specific interception storage parameter	$\mathrm{I}_{\mathrm{PFT}}$		
PFT-specific leaf area per unit of grid cell area	$\mathrm{LAI}_{\mathrm{PFT}}$		
daily precipitation	Pr	mm day^{-1}	
Soil evaporation	E_s	mm day^{-1}	
vegetation cover	f_v	%	
evaporation-available soil water	w_{evap}		
plant transpiration	E_T	mm day^{-1}	$E_T = \min(S, D) \cdot f_v$
daily water stress	ω		
Soil water supply	S		$S = E_{\max} \cdot w_r \cdot \mathrm{phen}_{\mathrm{PFT}}$
PFT-specific maximum water transport capacity	$E_{\max}$	mm day^{-1}	
water accessible for plants	w_r		$w_r = \sum_{l=1}^{n_{\mathrm{soil}}-1} w_l \cdot \mathrm{rootdist}_l$
relative water content at field capacity	w		
fraction of roots from surface to z	rootdist		$\mathrm{rootdist} = 1 - \beta_{\mathrm{root}}^{z}$
soil depth	z	mm	
root distribution parameter	β_{root}		
fraction of water that corresponds to their foliage projected cover	S_{PFT}		$S_{\mathrm{PFT}} = S \cdot \mathrm{FPC}_{\mathrm{PFT}}$
root biomass	$\mathrm{bm}_{\mathrm{root}}$	gC m^{-2}	
Atmospheric demand	D		$D = (1.0 - \mathrm{wet}) \cdot E_{\mathrm{eq}} \cdot \alpha_m / (1 + g_m/g_c)$
maximum Priestley-Taylor coefficient	α_m		
conductance scaling factor	g_m		
fraction of E_{eq} that was used to vaporize intercepted water from the canopy	wet		
homogeneous segments of length	L		
outflow of a linear reservoir cascade	Q_{out}		$Q_{\mathrm{out}}(t) = Q_{\mathrm{in}} \cdot \dfrac{1}{K \cdot \Gamma(n)} \left(\dfrac{t}{K}\right)^{n-1} \cdot \exp(-t/K)$
instantaneous inflow	Q_{in}		

Parameter/Variable	abbreviation	unit	Equation
gamma function	$\Gamma(n)$		
storage parameter	K		
linear reservoir segment of length	L	km	$K = \frac{L}{v}$
flow velocity	v	$\mathrm{m\ s^{-1}}$	
CFT-specific irrigation threshold	it		
amount of water required in the upper 50 cm soil	NIR	mm	$\mathrm{NIR} = W_{\mathrm{fc}} - w_a - w_{\mathrm{ice}}, \quad \mathrm{NIR} \geq 0$
available soil water	w_a	mm	
frozen soil water	w_{ice}	mm	
water at field capacity	W_{fc}	mm	
conveyance efficiency	E_c		
application requirements	AR	mm	$\mathrm{AR} = W_{\mathrm{sat}} - W_{fc} - W_{\mathrm{pwp}}) \cdot d_u - w_{\mathrm{fw}}, \quad \mathrm{AR} \geq 0$
gross irrigation requirements	GIR	mm	$\mathrm{GIR} = \frac{\mathrm{NIR+AR-Store}}{E_c}$
storage buffer	Store		
water distribution uniformity scalar	d_u		
available free water	w_{fw}	mm	
annual variation coefficients for precipitation	$\mathrm{CV_{prec}}$		
annual variation coefficients for temperature	$\mathrm{CV_{temp}}$		
biomass after the last harvest event	$\mathrm{MC_{leaf}}$	$\mathrm{gC\,m^{-2}}$	

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