CARDAMOM-FluxVal Version 1.0: a FLUXNET-based Validation System for CARDAMOM Carbon and Water Flux Estimates

Yan Yang[1], A. Anthony Bloom[1], Shuang Ma[1], Paul Levine[1], Alexander Norton[1], Nicholas C. Parazoo[1], John T. Reager[1], John Worden[1], Gregory R. Quetin[2], Luke Smallman[3,4], Williams Mathew[3,4], Liang Xu[1], Sassan Saatchi[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.
[2]Department of Earth System Science, Stanford University, Stanford, CA 94305, U.S.A.
[3]School of Geosciences, University of Edinburgh, Edinburgh, EH9 3FF, United Kingdom.
[4]National Centre for Earth Observation, Edinburgh EH9 3FF, United Kingdom.

Correspondence to: Yan Yang (yan.yang@jpl.nasa.gov)

S1. Model Description

1.1 CARDAMOM optimization of DALEC model parameters

The DALEC model estimates the projected ecosystem state as a function of the initial state (x_0), model parameters (p), and the corresponding meteorological and fire forcing (M, namely monthly temperature, precipitation, global radiation, vapor pressure deficit, and burned area) obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis Interim (ERA-interim) meteorology. At the site level, we used the Bayes Theorem to independently retrieve the optimal distribution of x0 and p given observations O for each tower site,

$$p(y|O) \propto p(y)p(O|y) \tag{1}$$

where y is the control vector $\{x_0, p\}$, $p(y)$ is the prior probability distribution of y, and $p(\boldsymbol{O}|\boldsymbol{y})$ is proportional to the likelihood of y given O, $L(\boldsymbol{y}|\boldsymbol{O})$. At each tower site, the observation vector O consists of measurements including the leaf area index (LAI), above- and below-ground biomass (ABGB), gross primary production (GPP), net ecosystem exchange (NEE) and evapotranspiration (ET). Assuming errors are uncorrelated – the overall likelihood of $\boldsymbol{y}$ given $\boldsymbol{O}$ can be expressed as

$$L(y|O) = L_{LAI}L_{ABGB}L_{GPP}L_{NEE}L_{ET} \tag{2}$$

For LAI, ABGB, GPP, NEE and ET, we derive the corresponding likelihood function L_* (i.e. L_{LAI}, L_{ABGB}, L_{GPP}, L_{NEE} and L_{ET}, respectively) as follows:

$$L_* = e^{-\frac{1}{2}\sum_i\left(\frac{m_i(y) - o_i}{\sigma_i}\right)^2} \tag{3}$$

where o_i and $m_i(y)$ correspond to the ith observation and the corresponding modelled quantity derived from control vector y, respectively; σ_i accounts for the combined errors from the DALEC model structure, forcing drivers and observations. To retrieve the distribution of $p(\boldsymbol{y}|\boldsymbol{O})$, we employed an adaptive metropolis-Hastings Markov Chain Monte Carlo (MHMCMC) approach following (Bloom et al., 2016; Haario et al., 2001). We ran 4 adaptive MHMCMC chains for 10^8 iterations in each tower sites.

1.2 Updated ET estimation

We used DALEC to represent the major pathways of water and terrestrial carbon cycle ((Bloom et al., 2020), and incorporated data assimilation by injecting in-situ observations (NEE, GPP, and ET) into the CARDAMOM model to make accurate predictions of various carbon pools and fluxes. The predicted flux variables were further validated using the independent observations. In addition, we included an improved parameterization of water use efficiency (WUE) into DALEC to optimize the ET prediction model by considering the effect of radiation (Boese et al., 2017). Incoming solar radiation (R_g) was found to be linearly correlated with the intercept term of the original water-use efficiency model that estimates ET based on gross primary productivity (GPP) and vapor pressure deficit of water (VPD). We therefore adopt the following equation for ET estimates:

$$ET = \frac{GPP \times VPD^{0.5}}{\mu WUE} + r \times R_g \quad (4)$$

where the new parameter (r) is the coefficient related to radiation, and modelled as w5 in the new CARDAMOM parameter list (Table S4).

1.3 Uncertainty of input data

The valid data range and associated uncertainty were modelled using empirical knowledge for each input variable participated in data assimilation, and listed in Table S1.

S2. Code Implementation

In order to reproduce the results presented in this study, readers can use the code and data stored at the Zenodo repository (Yang et al., 2021), and install the CARDAMOM model from the GitHub webpage: https://github.com/CARDAMOM-framework/CARDAMOM_v2.2. The instruction of CARDAMOM installation is in the MANUAL.md. All relevant CARDAMOM codes can also be found in the GitHub repository. Using the CARDAMOM model, one can reproduce the work in this study by running the Matlab code for FLUXNET-based validations (CARDAMOM_FLUXVAL_SITE_VALIDATION_METRICS.m). The code evaluates different validation metrics using .cbr files generated from CARDAMOM model and outputs the evaluations using flux data measured at selected FLUXNET sites. The validation results of interested flux variables (GPP, NEE and ET) rely on the matching of CARDAMOM model output and the corresponding validation sites. The evaluation metrics can be found in the subfolder, CARDAMOM-FLUXVAL_v1.0, under the MATLAB folder.

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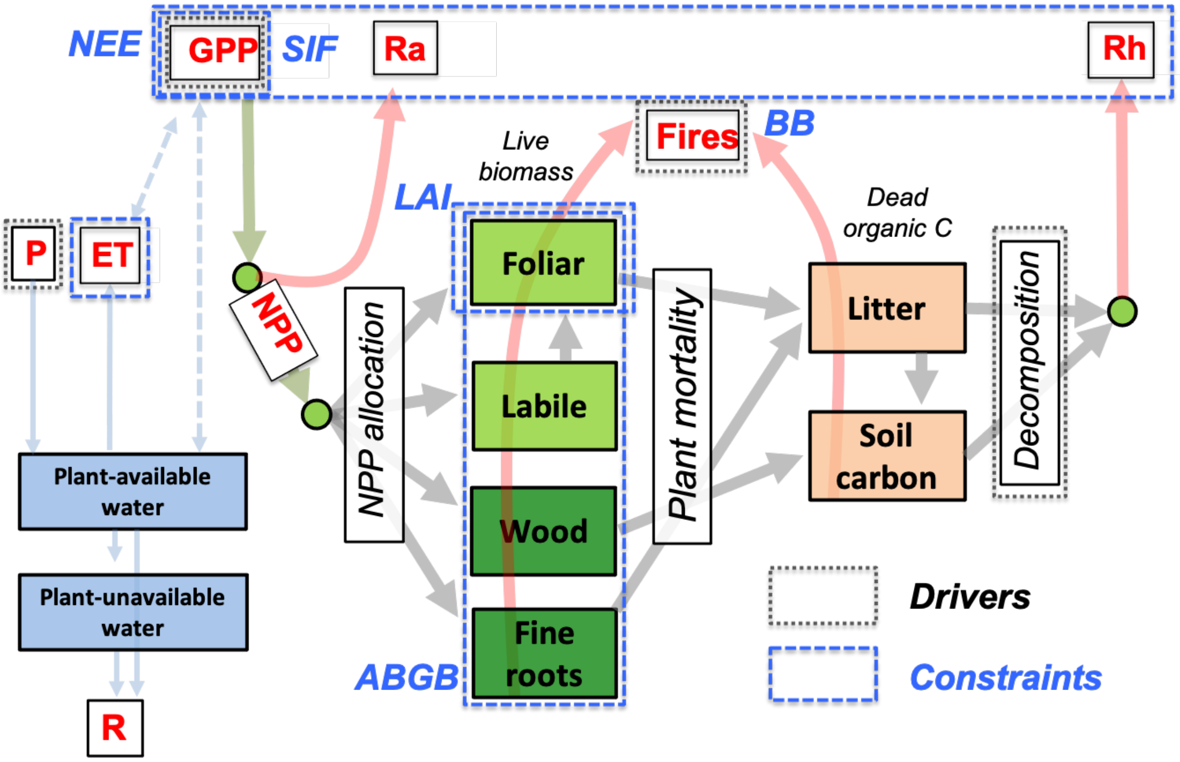
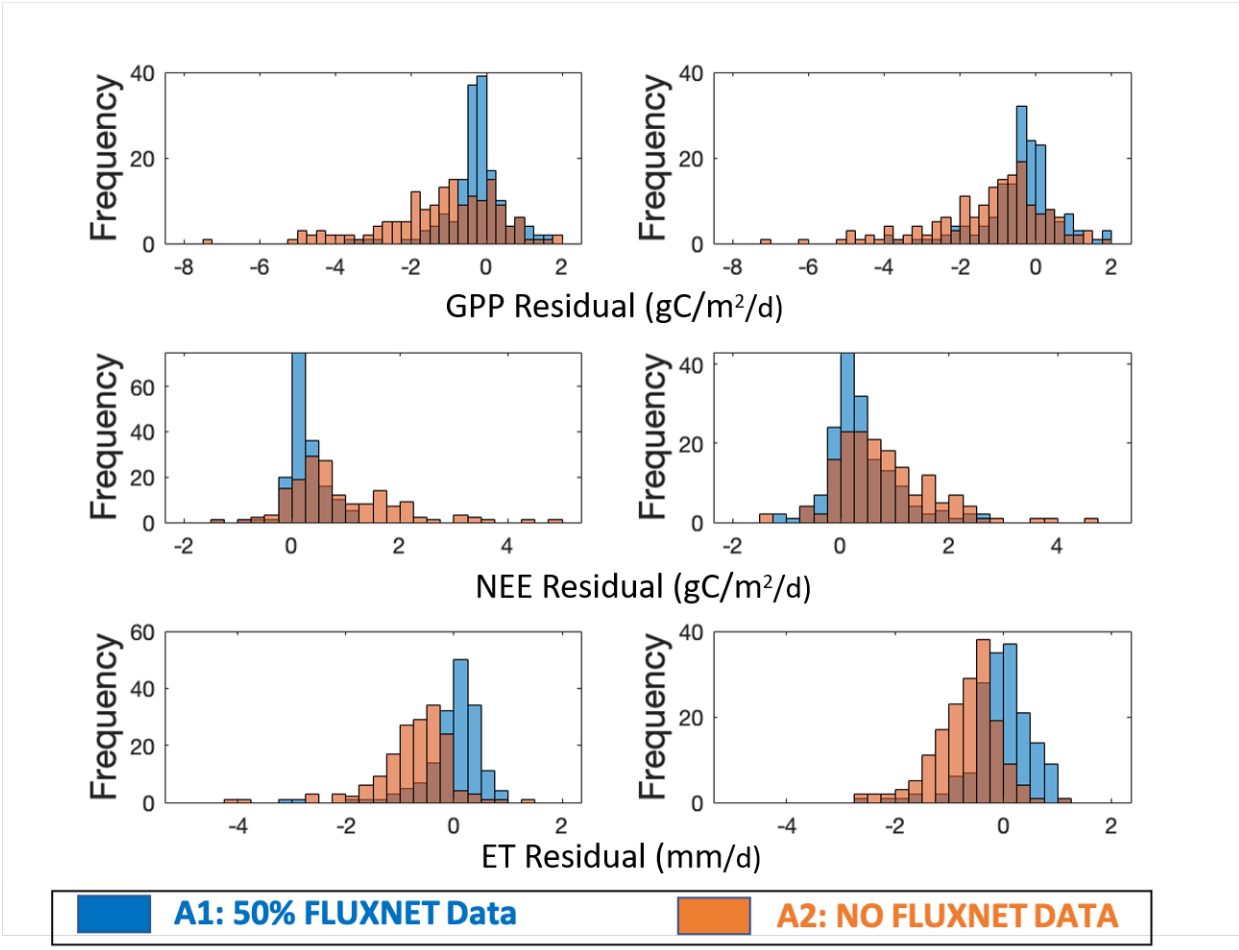


Figure S1. Diagram of the CARbon DAta-MOdel fraMework (CARDAMOM) Bayesian model-data fusion approach: the DALEC model (described in section 2.1) represents the ecosystem C and plant-available water balance; the dashed blue boxes denote the observational constraints used in this study. CARDAMOM is implemented at a 0.5°×0.5° resolution over all the Flux tower sites. Within each 0.5°×0.5° grid cell, DALEC model parameters and initial ecosystem states are optimized using an adaptive Metropolis-Hastings Markov Chain Monte Carlo algorithm.



. Figure S2. Histogram of annual-based residuals over all sites for the assimilation window (left panels) and prediction window (right panels). Residuals are the differences between model outputs (GPP, NEE and ET) and observations (GPP, NEE and ET measured at tower sites). Two different CARDAMOM runs are shown as "A1" and "A2" ("A1" means model simulations using 50% Fluxnet data - GPP, NEE and ET as constraints; "A2" means baseline model simulations with no Fluxnet data -GPP, NEE and ET constraints).

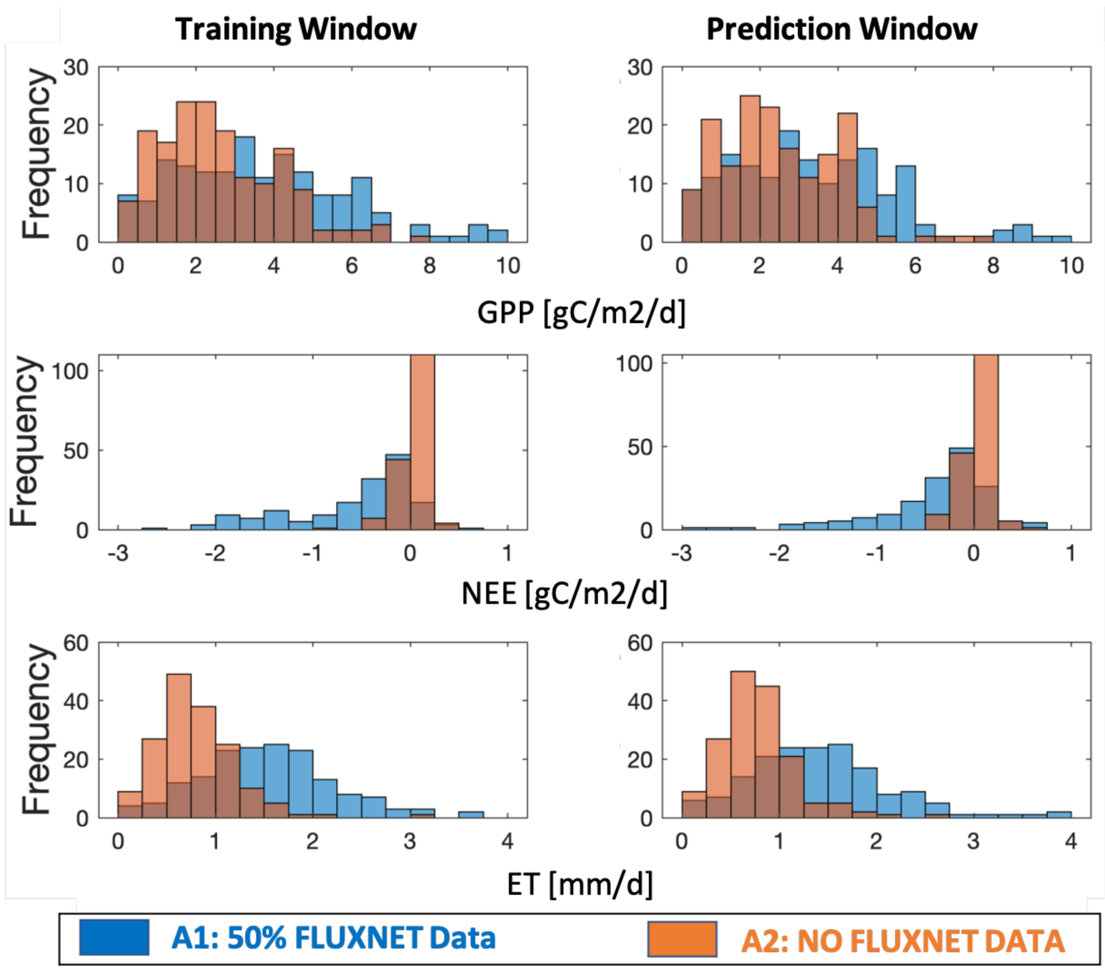


Figure S3. Histogram of site-level median model outputs (GPP, NEE and ET) over all sites for the assimilation window (left panels) and prediction window (right panels). Two different CARDAMOM runs are shown as "A1" and "A2" ("A1" means model simulations using 50% Fluxnet data - GPP, NEE and ET as constraints; "A2" means baseline model simulations with no Fluxnet data -GPP, NEE and ET constraints).

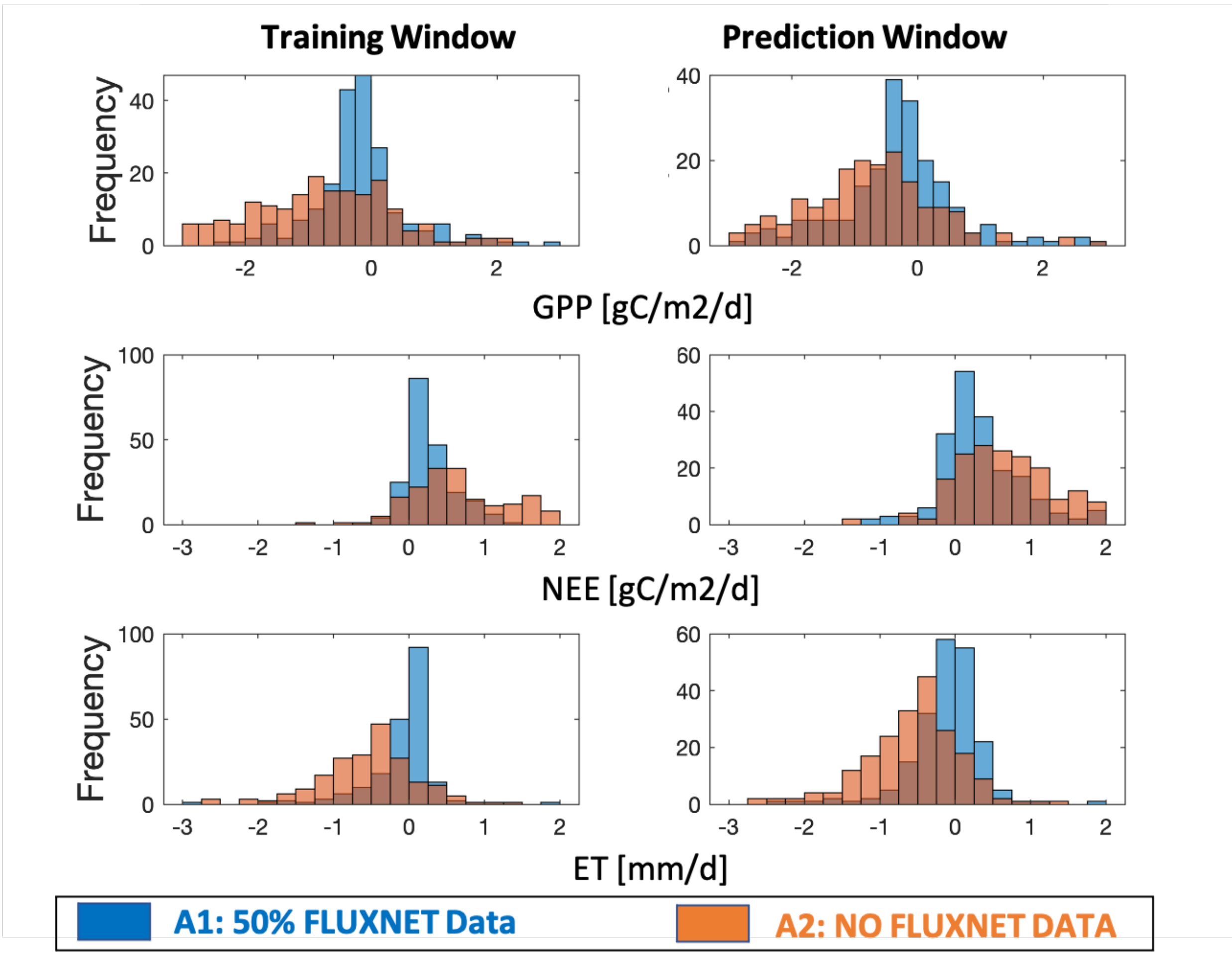


Figure S4. Histogram of site-level variable STD differences over all sites for the assimilation window (left panels) and prediction window (right panels). Variable STD differences are the standard deviation of model outputs (GPP, NEE and ET) for each site minus the standard deviation of Fluxnet tower measurements (GPP, NEE and ET). Two different CARDAMOM runs are shown as "A1" and "A2" ("A1" means model simulations using 50% Fluxnet data - GPP, NEE and ET as constraints; "A2" means baseline model simulations with no Fluxnet data -GPP, NEE and ET constraints).

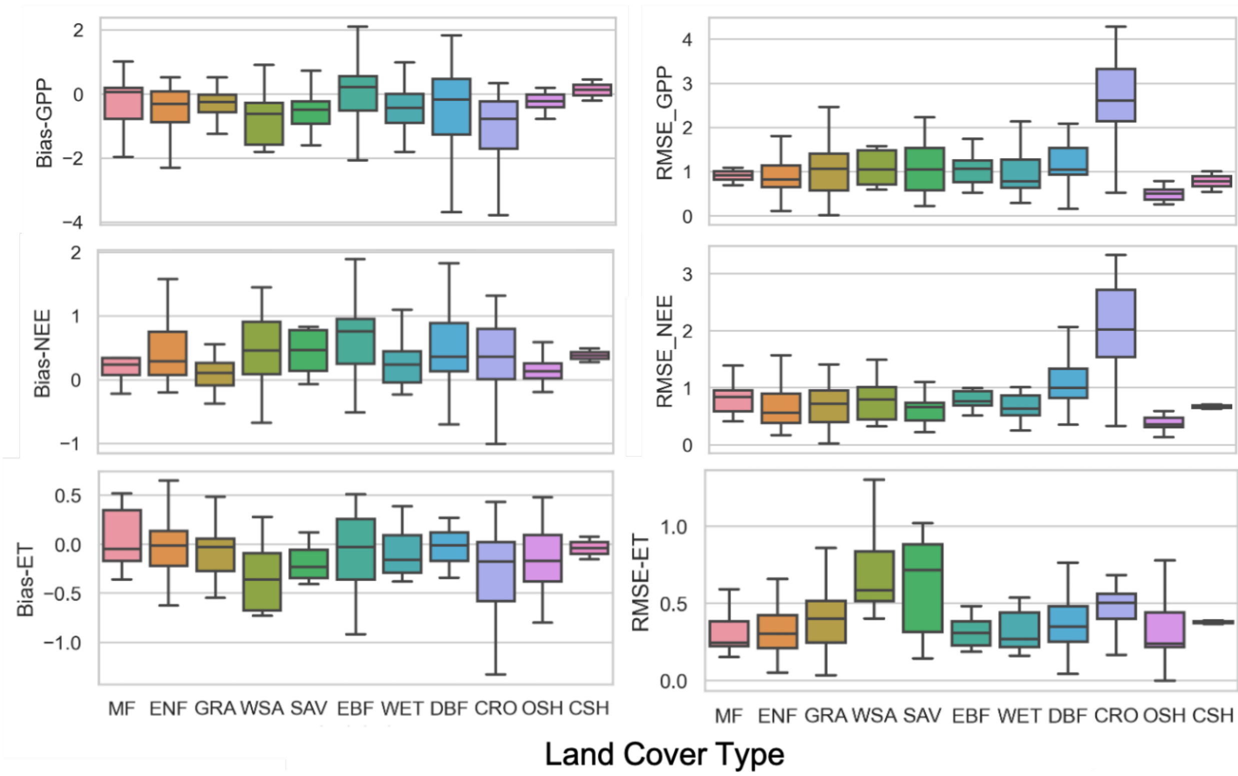


Figure S5. Box plots of correlation metrics (Bias and RMSE) for CARDAMOM outputs (GPP, NEE or ET) versus FLUXNET tower measurements with different landcover types (See table S3) within 95% confidence intervals.

Table S1. Data variables used for model assimilation and validation from satellite and inventory-based observations. The valid data range is range of data inputs to the CARDAMOM model assimilation, and uncertainty factor stands for the fraction of uncertainty relative to the input value.

Variables	Data source	Time range	Valid data range	Uncertainty
LAI	MOD15A2H (Myneni et al., 2015)	2001-2016	> 0 **	±log(1.2) *
ABGB	Xu et al, 2021	2015	> 0 **	$\pm\log(1.5)^4$ *
GPP	Fluxnet2015 (Pastorello et al., 2020)	2001-2015	> 0.1 **	Seasonal=±log(3) *
NEE	Fluxnet2015 (Pastorello et al., 2020)	2001-2015	-	Seasonal=$\pm 1 gC/m^{-2}d^{-1}$
ET	Fluxnet2015 (Pastorello et al., 2020)	2001-2015	> 0.1 **	Seasonal=±log(3) *

** Model and data are log-normalized*

***Data or model values below the valid range are rounded to the minimum (threshold) value*

Table S2. Statistical metrics used the study to evaluate model accuracies, parameter correlations, and residual analysis.

Symbol	Name	Equation	Parameters in the Equations
R	Pearson's linear correlation coefficient	$R = \frac{\sigma_{mo}}{\sigma_m \sigma_o}$	m_i and o_i are the model predicted values and observations for sample *i* out of the total sample size *n*; σ_{mo} is the covariance between the model simulation and observation; σ_m is the standard deviation of the model simulation; and σ_o is the standard deviation of the observations.
MEF	Nash and Sutcliffe model efficiency	$MEF = 1 - \frac{\sum_{i=1}^{n}(m_i - o_i)^2}{\sum_{i=1}^{n}(o_i - \bar{o})^2}$	
BIAS	Mean signed error	$BIAS = \frac{\sum_{i=1}^{n}(m_i - o_i)}{n}$	
RMSE	Root mean square error	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(m_i - o_i)^2}{n}}$	

Table S3. Statistics of landcover types and lengths of assimilation. The numbers in the table are the number of FLUXNET sites satisfying the conditions of land cover type and the length of assimilation (in years) for each row and column.

LC/Assimilation years	Years						
	<1	1~2	2~3	3~4	4~5	> 5	Total
DBF (Deciduous Broadleaf Forest)	5	7	0	5	3	6	26
EBF (Evergreen Broadleaf Forest)	1	7	1	3	0	3	15
ENF (Evergreen Needleleaf Forest)	8	15	6	3	3	14	49
MF (Mixed Forest)	1	1	1	1	1	4	9
SAV (Savannas)	0	4	2	1	0	0	7
CSH (Closed Shrublands)	0	1	0	0	0	1	2
OSH (Open Shrublands)	4	6	3	1	0	0	14
WET (Wetlands)	7	9	2	1	1	0	20
WSA (Woody Savannas)	2	1	0	0	1	2	6
CRO (Croplands)	4	5	1	3	4	3	20
GRA (Grasslands)	6	11	6	5	4	3	35
SNO (Snow)	1	0	0	0	0	0	1
Total	39	67	22	23	17	36	204

Table S4. Description of parameters used in the CARDAMOM model. The parameters were grouped to show their major contributions to different biophysical processes used in the model.

Parameters		Description	Prior Range
Allocation Parameters	A_1	Autotrophic respiration	0.2 - 0.8
	A_2	NPP fraction to foliar C	0.01 - 0.5
	A_3	NPP fraction to fine root C	0.01 - 0 .5
Turnover Parameters	T_1	Decomposition rate	0.00001-0.01
	T_2	Leaf Lifespan	1.01- 8
	T_3	Stem C turnover rate	2.5×10^{-5} - 10^{-3}
	T_4	Fine root C turnover rate	10^{-4} - 10^{-2}
	T_5	Litter C turnover rate at $\boldsymbol{T}$, $\boldsymbol{P}$	10^{-4} - 10^{-2}
	T_6	Soil organic matter (SOM) turnover rate at $\boldsymbol{T}$, $\boldsymbol{P}$	10^{-7} - 10^{-3}
	T_7	Heterotrophic temperature dependence factor	0.018 - 0.08
	T_8	Moisture factor	0.01-1
Canopy Parameters	C_1	Canopy Efficiency	5 – 50
	C_2	Leaf onset day	0 – 365.25
	C_3	Annual labile C release fraction	1/8 - 1
	C_4	Labile Release period	10 – 100 days
	C_5	Leaf fall day	0 – 365.25
	C_6	Leaf fall period	20 – 150 days
	C_7	Leaf C mass per area	5 – 200 gC/m^2
	C_8	Wilting point	1-100000
	C_9	Lab pool lifespan	1.001-8
Initial Conditions	I_1	Labile C at time t	1 – 2000 gC/m^{-2}
	I_2	Foliar C at time t	1 – 2000 gC/m^{-2}

	I_3	Fine root C at time t	1 – 2000 gC/m^{-2}
	I_4	Above-and below-ground woodyC at time t	1 – 10^5 gC/m-2
	I_5	Litter C at time t	1 – 2000 gC/m^{-2}
	I_6	Soil organic C at time t	1 – 2×10^5 gC/m^{-2}
	I_7	Bucket at t0	1-100000
	I_8	Plant-Unavailable Water pool	1-100000
Water Parameters	w_1	Inherent water-use efficiency	0.5-30 hPa gC/kg H_2O
	w_2	Runoff focal point (~maximum soil storage capacity x 4)	1-100000
	w_3	Plant-Unavailable Water runoff fraction	0.01-1
	w_4	Plant-Unavailable Water Runoff focal point	1-100000
	w_5	Radiation Coefficient	0.01-0.3
Fire Parameters	F_1	Combustion factors of foliar C	0.01 - 1
	F_2	Combustion factors of non-foliar biomass C	0.01 - 1
	F_3	Combustion factor of soil C	0.01 - 1
	F_4	Resilience factor	0.01 - 1

Table S5. The description of the FLUXNET sites

Site ID	Site Name	Lat	Lon	IGBP	Available
AR-SLu	San Luis	-33.4648	-66.4598	MF	2009-2011
AR-Vir	Virasoro	-28.2395	-56.1886	ENF	2009-2012
AT-Neu	Neustift	47.1167	11.3175	GRA	2002-2012
AU-Ade	Adelaide River	-13.0769	131.1178	WSA	2010-2014
AU-ASM	Alice Springs	-22.283	133.249	ENF	2007-2009
AU-Cpr	Calperum	-34.0021	140.5891	SAV	2010-2014
AU-Cum	Cumberland Plain	-33.6152	150.7236	EBF	2012-2014
AU-DaP	Daly River Savanna	-14.0633	131.3181	GRA	2007-2013
AU-DaS	Daly River Cleared	-14.1593	131.3881	SAV	2008-2014
AU-Dry	Dry River	-15.2588	132.3706	SAV	2008-2014
AU-Emr	Emerald	-23.8587	148.4746	GRA	2011-2013
AU-Fog	Fogg Dam	-12.5452	131.3072	WET	2006-2008
AU-Gin	Gingin	-31.3764	115.7138	WSA	2011-2014
AU-GWW	Great Western Woodlands, Western Australia, Australia	-30.1913	120.6541	SAV	2013-2014
AU-How	Howard Springs	-12.4943	131.1523	WSA	2001-2014
AU-Lox	Loxton	-34.4704	140.6551	DBF	2008-2009
AU-RDF	Red Dirt Melon Farm, Northern Territory	-14.5636	132.4776	WSA	2011-2013
AU-Rig	Riggs Creek	-36.6499	145.5759	GRA	2011-2014
AU-Rob	Robson Creek, Queensland, Australia	-17.1175	145.6301	EBF	2014-2014
AU-Stp	Sturt Plains	-17.1507	133.3502	GRA	2008-2014
AU-TTE	Ti Tree East	-22.287	133.64	OSH	2012-2014
AU-Tum	Tumbarumba	-35.6566	148.1517	EBF	2001-2014
AU-Wac	Wallaby Creek	-37.4259	145.1878	EBF	2005-2008
AU-Whr	Whroo	-36.6732	145.0294	EBF	2011-2014
AU-Wom	Wombat	-37.4222	144.0944	EBF	2010-2014
AU-Ync	Jaxa	-34.9893	146.2907	GRA	2012-2014
BE-Bra	Brasschaat	51.3076	4.5198	MF	1996-2014
BE-Lon	Lonzee	50.5516	4.7461	CRO	2004-2014
BE-Vie	Vielsalm	50.305	5.9981	MF	1996-2014
BR-Sa1	Santarem-Km67-Primary Forest	-2.8567	-54.9589	EBF	2002-2011
BR-Sa3	Santarem-Km83-Logged Forest	-3.018	-54.9714	EBF	2000-2004
CA-Gro	Ontario - Groundhog River, Boreal Mixedwood Forest	48.2167	-82.1556	MF	2003-2014
CA-Man	Manitoba - Northern Old Black Spruce (former BOREAS Northern Study Area)	55.8796	-98.4808	ENF	1994-2008
CA-NS1	UCI-1850 burn site	55.8792	-98.4839	ENF	2001-2005
CA-NS2	UCI-1930 burn site	55.9058	-98.5247	ENF	2001-2005
CA-NS3	UCI-1964 burn site	55.9117	-98.3822	ENF	2001-2005

CA-NS4	UCI-1964 burn site wet	55.9144	-98.3806	ENF	2002-2005
CA-NS5	UCI-1981 burn site	55.8631	-98.485	ENF	2001-2005
CA-NS6	UCI-1989 burn site	55.9167	-98.9644	OSH	2001-2005
CA-NS7	UCI-1998 burn site	56.6358	-99.9483	OSH	2002-2005
CA-Oas	Saskatchewan - Western Boreal, Mature Aspen	53.6289	-106.1978	DBF	1996-2010
CA-Obs	Saskatchewan - Western Boreal, Mature Black Spruce	53.9872	-105.1178	ENF	1997-2010
CA-Qfo	Quebec - Eastern Boreal, Mature Black Spruce	49.6925	-74.3421	ENF	2003-2010
CA-SF1	Saskatchewan - Western Boreal, forest burned in 1977	54.485	-105.8176	ENF	2003-2006
CA-SF2	Saskatchewan - Western Boreal, forest burned in 1989	54.2539	-105.8775	ENF	2001-2005
CA-SF3	Saskatchewan - Western Boreal, forest burned in 1998	54.0916	-106.0053	OSH	2001-2006
CA-TP1	Ontario - Turkey Point 2002 Plantation White Pine	42.6609	-80.5595	ENF	2002-2014
CA-TP2	Ontario - Turkey Point 1989 Plantation White Pine	42.7744	-80.4588	ENF	2002-2007
CA-TP3	Ontario - Turkey Point 1974 Plantation White Pine	42.7068	-80.3483	ENF	2002-2014
CA-TP4	Ontario - Turkey Point 1939 Plantation White Pine	42.7102	-80.3574	ENF	2002-2014
CA-TPD	Ontario - Turkey Point Mature Deciduous	42.6353	-80.5577	DBF	2012-2014
CG-Tch	Tchizalamou	-4.2892	11.6564	SAV	2006-2009
CH-Cha	Chamau	47.2102	8.4104	GRA	2005-2014
CH-Dav	Davos	46.8153	9.8559	ENF	1997-2014
CH-Fru	Früebüel	47.1158	8.5378	GRA	2005-2014
CH-Lae	Laegern	47.4781	8.365	MF	2004-2014
CH-Oe1	Oensingen grassland	47.2858	7.7319	GRA	2002-2008
CH-Oe2	Oensingen crop	47.2863	7.7343	CRO	2004-2014
CN-Cha	Changbaishan	42.4025	128.0958	MF	2003-2005
CN-Cng	Changling	44.5934	123.5092	GRA	2007-2010
CN-Dan	Dangxiong	30.4978	91.0664	GRA	2004-2005
CN-Din	Dinghushan	23.1733	112.5361	EBF	2003-2005
CN-Du2	Duolun_grassland (D01)	42.0467	116.2836	GRA	2006-2008
CN-Du3	Duolun Degraded Meadow	42.0551	116.2809	GRA	2009-2010
CN-Ha2	Haibei Shrubland	37.6086	101.3269	WET	2003-2005
CN-HaM	Haibei Alpine Tibet site	37.37	101.18	GRA	2002-2004
CN-Qia	Qianyanzhou	26.7414	115.0581	ENF	2003-2005
CN-Sw2	Siziwang Grazed (SZWG)	41.7902	111.8971	GRA	2010-2012
CZ-BK1	Bily Kriz forest	49.5021	18.5369	ENF	2004-2014
CZ-BK2	Bily Kriz grassland	49.4944	18.5429	GRA	2004-2012
CZ-wet	Trebon (CZECHWET)	49.0247	14.7704	WET	2006-2014
DE-Akm	Anklam	53.8662	13.6834	WET	2009-2014
DE-Geb	Gebesee	51.1001	10.9143	CRO	2001-2014

DE-Gri	Grillenburg	50.95	13.5126	GRA	2004-2014
DE-Hai	Hainich	51.0792	10.453	DBF	2000-2012
DE-Kli	Klingenberg	50.8931	13.5224	CRO	2004-2014
DE-Lkb	Lackenberg	49.0996	13.3047	ENF	2009-2013
DE-Lnf	Leinefelde	51.3282	10.3678	DBF	2002-2012
DE-Obe	Oberbärenburg	50.7867	13.7213	ENF	2008-2014
DE-RuR	Rollesbroich	50.6219	6.3041	GRA	2011-2014
DE-RuS	Selhausen Juelich	50.8659	6.4472	CRO	2011-2014
DE-Seh	Selhausen	50.8706	6.4497	CRO	2007-2010
DE-SfN	Schechenfilz Nord	47.8064	11.3275	WET	2012-2014
DE-Spw	Spreewald	51.8923	14.0337	WET	2010-2014
DE-Tha	Tharandt	50.9624	13.5652	ENF	1996-2014
DE-Zrk	Zarnekow	53.8759	12.889	WET	2013-2014
DK-Eng	Enghave	55.6905	12.1918	GRA	2005-2008
DK-Fou	Foulum	56.4842	9.5872	CRO	2005-2005
DK-Sor	Soroe	55.4859	11.6446	DBF	1996-2014
ES-Amo	Amoladeras	36.8336	-2.2523	OSH	2007-2012
ES-LgS	Laguna Seca	37.0979	-2.9658	OSH	2004-2013
ES-LJu	Llano de los Juanes	36.9266	-2.7521	OSH	2007-2009
ES-Ln2	Lanjaron-Salvage logging	36.9695	-3.4758	OSH	2009-2009
FI-Hyy	Hyytiala	61.8474	24.2948	ENF	1996-2014
FI-Jok	Jokioinen	60.8986	23.5135	CRO	2000-2003
FI-Let	Lettosuo	60.6418	23.9595	ENF	2009-2012
FI-Lom	Lompolojankka	67.9972	24.2092	WET	2007-2009
FI-Sod	Sodankyla	67.3624	26.6386	ENF	2001-2014
FR-Fon	Fontainebleau-Barbeau	48.4764	2.7801	DBF	2005-2014
FR-Gri	Grignon	48.8442	1.9519	CRO	2004-2014
FR-LBr	Le Bray	44.7171	-0.7693	ENF	1996-2008
FR-Pue	Puechabon	43.7413	3.5957	EBF	2000-2014
GF-Guy	Guyaflux (French Guiana)	5.2788	-52.9249	EBF	2004-2014
GH-Ank	Ankasa	5.2685	-2.6942	EBF	2011-2014
DK-NuF	Nuuk Fen	64.1308	-51.3861	WET	2008-2014
DK-ZaF	Zackenberg Fen	74.4814	-20.5545	WET	2008-2011
DK-ZaH	Zackenberg Heath	74.4733	-20.5503	GRA	2000-2014
IT-BCi	Borgo Cioffi	40.5238	14.9574	CRO	2004-2014
IT-CA1	Castel d'Asso1	42.3804	12.0266	DBF	2011-2014
IT-CA2	Castel d'Asso2	42.3772	12.026	CRO	2011-2014
IT-CA3	Castel d'Asso 3	42.38	12.0222	DBF	2011-2014
IT-Col	Collelongo	41.8494	13.5881	DBF	1996-2014

IT-Cp2	Castelporziano2	41.7043	12.3573	EBF	2012-2014
IT-Cpz	Castelporziano	41.7053	12.3761	EBF	1997-2009
IT-Isp	Ispra ABC-IS	45.8126	8.6336	DBF	2013-2014
IT-La2	Lavarone2	45.9542	11.2853	ENF	2000-2002
IT-Lav	Lavarone	45.9562	11.2813	ENF	2003-2014
IT-MBo	Monte Bondone	46.0147	11.0458	GRA	2003-2013
IT-Noe	Arca di Noe - Le Prigionette	40.6062	8.1512	CSH	2004-2014
IT-PT1	Parco Ticino forest	45.2009	9.061	DBF	2002-2004
IT-Ren	Renon	46.5869	11.4337	ENF	1998-2013
IT-Ro1	Roccarespampani 1	42.4081	11.93	DBF	2000-2008
IT-Ro2	Roccarespampani 2	42.3903	11.9209	DBF	2002-2012
IT-SR2	San Rossore 2	43.732	10.291	ENF	2013-2014
IT-SRo	San Rossore	43.7279	10.2844	ENF	1999-2012
IT-Tor	Torgnon	45.8444	7.5781	GRA	2008-2014
JP-MBF	Moshiri Birch Forest Site	44.3869	142.3186	DBF	2003-2005
JP-SMF	Seto Mixed Forest Site	35.2617	137.0788	MF	2002-2006
MY-PSO	Pasoh Forest Reserve (PSO)	2.973	102.3062	EBF	2003-2009
NL-Hor	Horstermeer	52.2404	5.0713	GRA	2004-2011
NL-Loo	Loobos	52.1666	5.7436	ENF	1996-2014
PA-SPn	Sardinilla Plantation	9.3181	-79.6346	DBF	2007-2009
PA-SPs	Sardinilla-Pasture	9.3138	-79.6314	GRA	2007-2009
RU-Che	Cherski	68.613	161.3414	WET	2002-2005
RU-Cok	Chokurdakh	70.8291	147.4943	OSH	2003-2014
RU-Fyo	Fyodorovskoye	56.4615	32.9221	ENF	1998-2014
RU-Ha1	Hakasia steppe	54.7252	90.0022	GRA	2002-2004
SD-Dem	Demokeya	13.2829	30.4783	SAV	2005-2009
NO-Adv	Adventdalen	78.186	15.923	WET	2011-2014
NO-Blv	Bayelva, Spitsbergen	78.9216	11.8311	SNO	2008-2009
SN-Dhr	Dahra	15.4028	-15.4322	SAV	2010-2013
US-AR1	ARM USDA UNL OSU Woodward Switchgrass 1	36.4267	-99.42	GRA	2009-2012
US-AR2	ARM USDA UNL OSU Woodward Switchgrass 2	36.6358	-99.5975	GRA	2009-2012
US-ARM	ARM Southern Great Plains site- Lamont	36.6058	-97.4888	CRO	2003-2012
US-ARb	ARM Southern Great Plains burn site- Lamont	35.5497	-98.0402	GRA	2005-2006
US-ARc	ARM Southern Great Plains control site- Lamont	35.5465	-98.04	GRA	2005-2006
US-Atq	Atqasuk	70.4696	-157.4089	WET	2003-2008
US-Blo	Blodgett Forest	38.8953	-120.6328	ENF	1997-2007
US-CRT	Curtice Walter-Berger cropland	41.6285	-83.3471	CRO	2011-2013
US-Cop	Corral Pocket	38.09	-109.39	GRA	2001-2007
US-GBT	GLEES Brooklyn Tower	41.3658	-106.2397	ENF	1999-2006

US-GLE	GLEES	41.3665	-106.2399	ENF	2004-2014
US-Goo	Goodwin Creek	34.2547	-89.8735	GRA	2002-2006
US-Ha1	Harvard Forest EMS Tower (HFR1)	42.5378	-72.1715	DBF	1991-2012
US-IB2	Fermi National Accelerator Laboratory- Batavia (Prairie site)	41.8406	-88.241	GRA	2004-2011
US-Ivo	Ivotuk	68.4865	-155.7503	WET	2004-2007
US-KS1	Kennedy Space Center (slash pine)	28.4583	-80.6709	ENF	2002-2002
US-KS2	Kennedy Space Center (scrub oak)	28.6086	-80.6715	CSH	2003-2006
US-Lin	Lindcove Orange Orchard	36.3566	-119.8423	CRO	2009-2010
US-Los	Lost Creek	46.0827	-89.9792	WET	2000-2014
US-MMS	Morgan Monroe State Forest	39.3232	-86.4131	DBF	1999-2014
US-Me1	Metolius - Eyerly burn	44.5794	-121.5	ENF	2004-2005
US-Me2	Metolius mature ponderosa pine	44.4523	-121.5574	ENF	2002-2014
US-Me3	Metolius-second young aged pine	44.3154	-121.6078	ENF	2004-2009
US-Me5	Metolius-first young aged pine	44.4372	-121.5668	ENF	2000-2002
US-Me6	Metolius Young Pine Burn	44.3233	-121.6078	ENF	2010-2014
US-Myb	Mayberry Wetland	38.0498	-121.7651	WET	2010-2014
US-NR1	Niwot Ridge Forest (LTER NWT1)	40.0329	-105.5464	ENF	1998-2014
US-Ne1	Mead - irrigated continuous maize site	41.1651	-96.4766	CRO	2001-2013
US-Ne2	Mead - irrigated maize-soybean rotation site	41.1649	-96.4701	CRO	2001-2013
US-Ne3	Mead - rainfed maize-soybean rotation site	41.1797	-96.4397	CRO	2001-2013
US-ORv	Olentangy River Wetland Research Park	40.0201	-83.0183	WET	2011-2011
US-Oho	Oak Openings	41.5545	-83.8438	DBF	2004-2013
US-PFa	Park Falls/WLEF	45.9459	-90.2723	MF	1995-2014
US-Prr	Poker Flat Research Range Black Spruce Forest	65.1237	-147.4876	ENF	2010-2014
US-SRC	Santa Rita Creosote	31.9083	-110.8395	OSH	2008-2014
US-SRG	Santa Rita Grassland	31.7894	-110.8277	GRA	2008-2014
US-SRM	Santa Rita Mesquite	31.8214	-110.8661	WSA	2004-2014
US-Sta	Saratoga	41.3966	-106.8024	OSH	2005-2009
US-Syv	Sylvania Wilderness Area	46.242	-89.3477	MF	2001-2014
US-Ton	Tonzi Ranch	38.4316	-120.966	WSA	2001-2014
US-Tw1	Twitchell Wetland West Pond	38.1074	-121.6469	WET	2012-2014
US-Tw2	Twitchell Corn	38.1047	-121.6433	CRO	2012-2013
US-Tw3	Twitchell Alfalfa	38.1159	-121.6467	CRO	2013-2014
US-Tw4	Twitchell East End Wetland	38.103	-121.6414	WET	2013-2014
US-Twt	Twitchell Island	38.1087	-121.653	CRO	2009-2014
US-UMB	Univ. of Mich. Biological Station	45.5598	-84.7138	DBF	2000-2014
US-UMd	UMBS Disturbance	45.5625	-84.6975	DBF	2007-2014
US-Var	Vaira Ranch- Ione	38.4133	-120.9507	GRA	2000-2014

US-WCr	Willow Creek	45.8059	-90.0799	DBF	1999-2014
US-WPT	Winous Point North Marsh	41.4646	-82.9962	WET	2011-2013
US-Whs	Walnut Gulch Lucky Hills Shrub	31.7438	-110.0522	OSH	2007-2014
US-Wi0	Young red pine (YRP)	46.6188	-91.0814	ENF	2002-2002
US-Wi1	Intermediate hardwood (IHW)	46.7305	-91.2329	DBF	2003-2003
US-Wi2	Intermediate red pine (IRP)	46.6869	-91.1528	ENF	2003-2003
US-Wi3	Mature hardwood (MHW)	46.6347	-91.0987	DBF	2002-2004
US-Wi4	Mature red pine (MRP)	46.7393	-91.1663	ENF	2002-2005
US-Wi5	Mixed young jack pine (MYJP)	46.6531	-91.0858	ENF	2004-2004
US-Wi6	Pine barrens #1 (PB1)	46.6249	-91.2982	OSH	2002-2003
US-Wi7	Red pine clearcut (RPCC)	46.6491	-91.0693	OSH	2005-2005
US-Wi8	Young hardwood clearcut (YHW)	46.7223	-91.2524	DBF	2002-2002
US-Wi9	Young Jack pine (YJP)	46.6188	-91.0814	ENF	2004-2005
US-Wkg	Walnut Gulch Kendall Grasslands	31.7365	-109.9419	GRA	2004-2014
ZM-Mon	Mongu	-15.4378	23.2528	DBF	2000-2009

Table S6 drivers (2001-2016) of the CARDAMOM model

Name	Unit
Time	Days since 01/01/2001
Min Temperature	°C
Max Temperature	°C
Solar irradiance	$MJ/m^2/day$
CO_2	ppm
Day of Year	day
Burned Area	m^2/m^2
VPD	hPa
Precipitation	mm/day