Supplement of Geosci. Model Dev., 15, 9111–9125, 2022
https://doi.org/10.5194/gmd-15-9111-2022-supplement

Geoscientific Model Development
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EGU

Supplement of

Evaluating the vegetation–atmosphere coupling strength of ORCHIDEE land surface model (v7266)

Yuan Zhang et al.

Correspondence to: Yuan Zhang (yuan.zhang@lsce.ipsl.fr)

Supplementary

Calibration of a1, b1 parameters in ORCHIDEE.

In ORCHIDEE-trunk, the stomatal conductance formulation of (*Yin and Struik*, 2009) is used:

$$g_s = g_0 + \frac{A+R_d}{C_i - C_{i*}} f_{vpd} \quad \text{(S1)}$$

Where g_0 is the residual stomatal conductance if the irradiance approaches zero, C_{i*} is the C_i based CO_2 compensation point in the absence of R_d, and f_{vpd} is the function for the effect of leaf-to-air vapour pressure difference (VPD), and is described empirically as:

$$f_{vpd} = \frac{1}{\frac{1}{a_1 - b_1 VPD} - 1} \quad \text{(S2)}$$

Where a_1 and b_1 are empirical constants.

Comparing Equation (S1) with Ball-Berry model equation used in (*Lin et al.*, 2015):

$$g_s = 1.6 \left(1 + \frac{g_1}{\sqrt{VPD}}\right) \frac{A}{C_a} \quad \text{(S3)}$$

Where g_1 is the model co-efficient, C_a is the CO_2 concentration at the leaf surface (ppm).

Taking $C_i = C_a - \frac{A}{g_s}$, $A + R_d = A_{net} = A$ and substituting in Equation (S1), we obtain:

$$(C_a - C_{i*}) g_s^2 - \left(A + A f_{vpd}\right) g_s + g_0 (C_a - C_{i*}) + g_0 A = 0$$

If $g_0 = 0$ and $C_a - C_{i*} = C_a$

$$C_a \; g_s \; - \left(A + A f_{vpd}\right) = 0$$

Further simplifying above equation,

$$g_s = \left(1 + f_{vpd}\right) * \frac{A}{C_a} \quad \text{(S4)}$$

Equating equations (S3) and (S4),

$$f_{vpd} = 0.6 + \frac{1.6g_1}{\sqrt{VPD}} \quad \text{(S5)}$$

Solving equations (S2) and (S5) and using g_1 values for different PFTs from (*Lin et al.*, 2015), we get a corresponding a_1 and b_1 values. See Table S2 for different PFTs a_1 and b_1 values estimated by constraining g_1 values from (*Lin et al.*, 2015).

Figure S1 The stomatal conductance model co-efficient in ORCHIDEE (f_{vpd}) which is equivalent (g_1) Lin et al. (2015). f_{vpd} in ORCHIDEE is a function of vapor pressure deficit (VPD) and empirical parameters a_1 and b_1. f_{vpd} is plotted against arbitrary values of VPD with different a_1, b_1 values from default ORCHIDEE (Yin and Struik, 2009) and Lin et al. (2015).

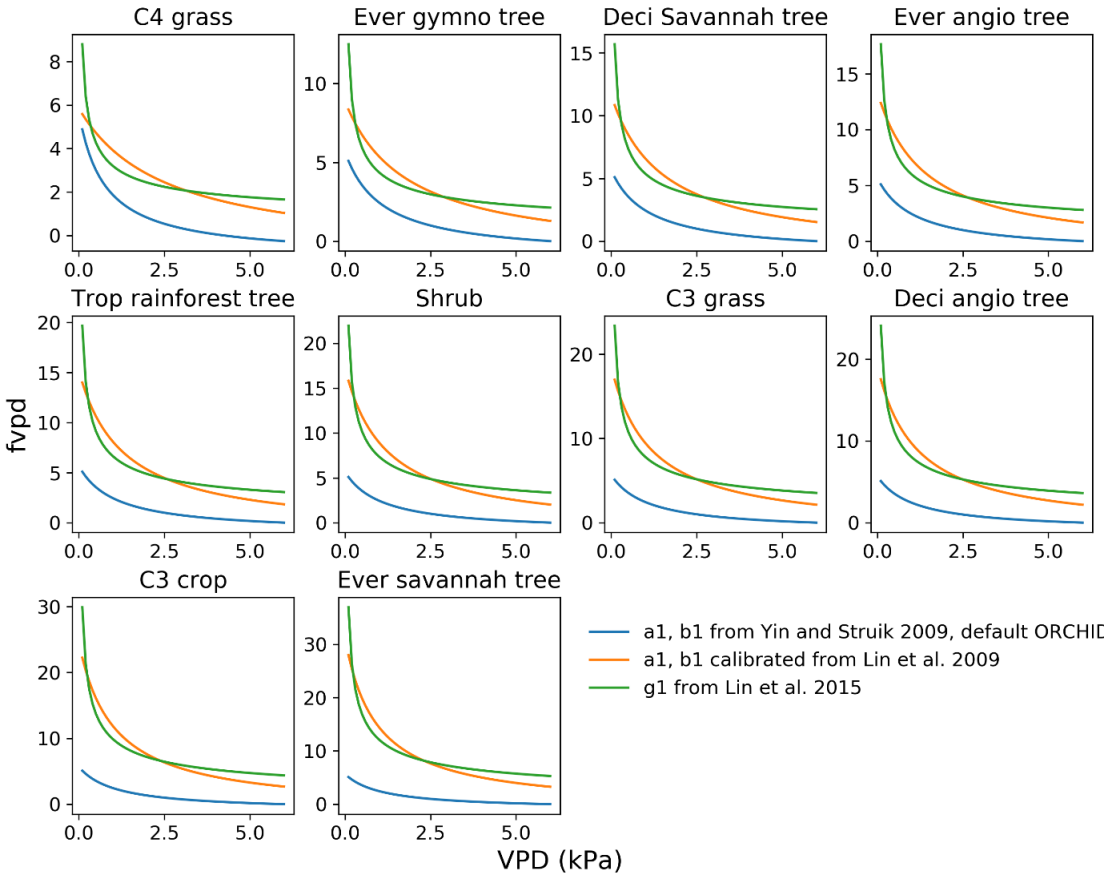

Figure S2 Performance of random forest models in the validation datasets

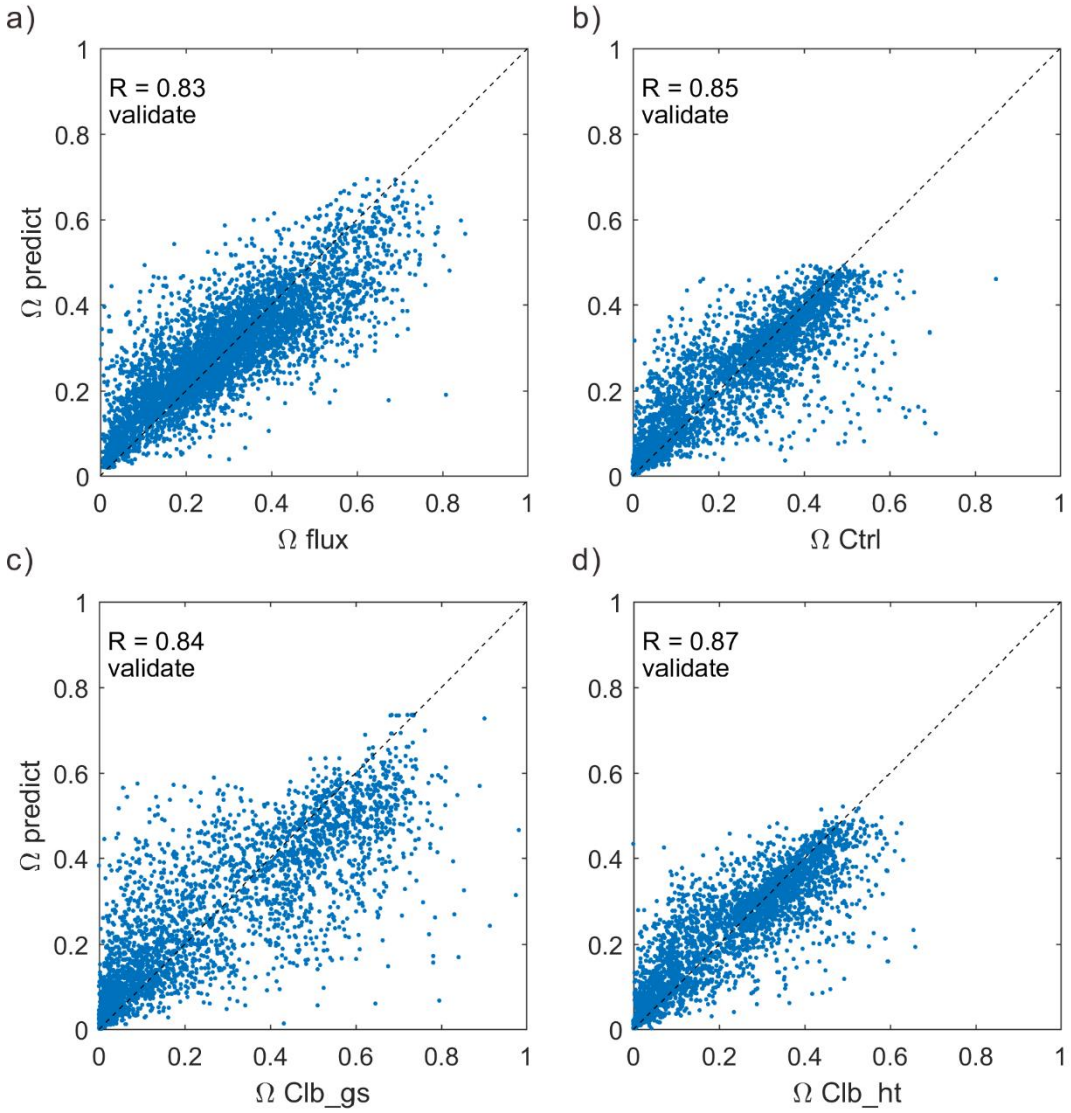

Figure S3. An example to explain the SHAP values. For this data sample, the Ω value (0.2) is smaller than the base value (all sample mean Ω of 0.29). SHAP values show the contribution of each factor. i.e. the PFT type of this data is expected to cause a decrease of Ω from the base value by 0.0708, etc.

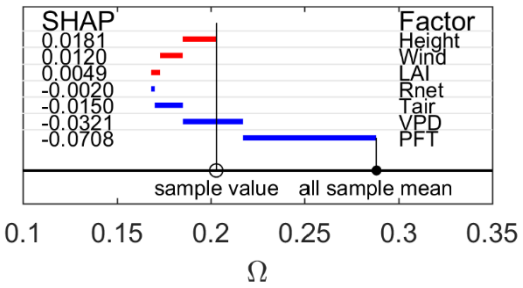

Figure S4 Same as Figure 7 but for Gs SHAP values.

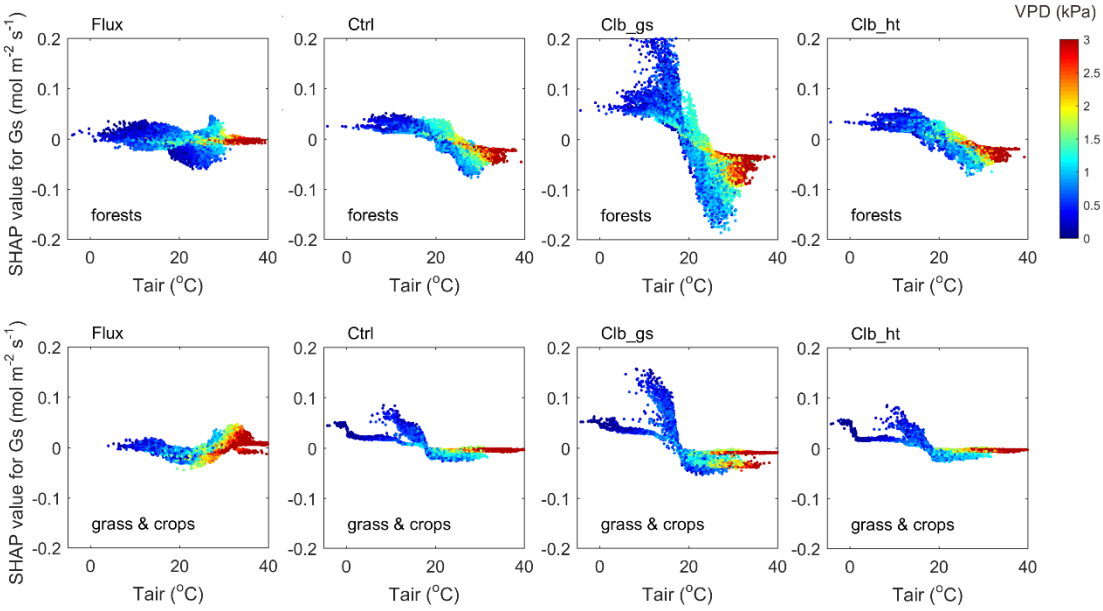

Figure S5. The dependence of Ga on LAI and different canopy heights in ORCHIDEE parameterization under 3 m s^{-1} wind speed, sea level pressure and 15 ℃ condition

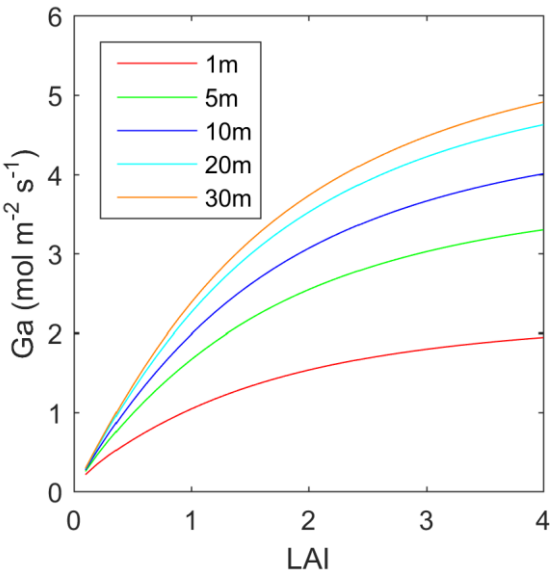

Figure S6. Impacts of uncertainties in the empirical calculation of Ω on the comparison. The boxes from the left to right: Ctrl simulation, De Kauwe et al. (2017) dataset, increasing Ga by 30%, decreasing Ga by 30%, correction of the energy imbalance.

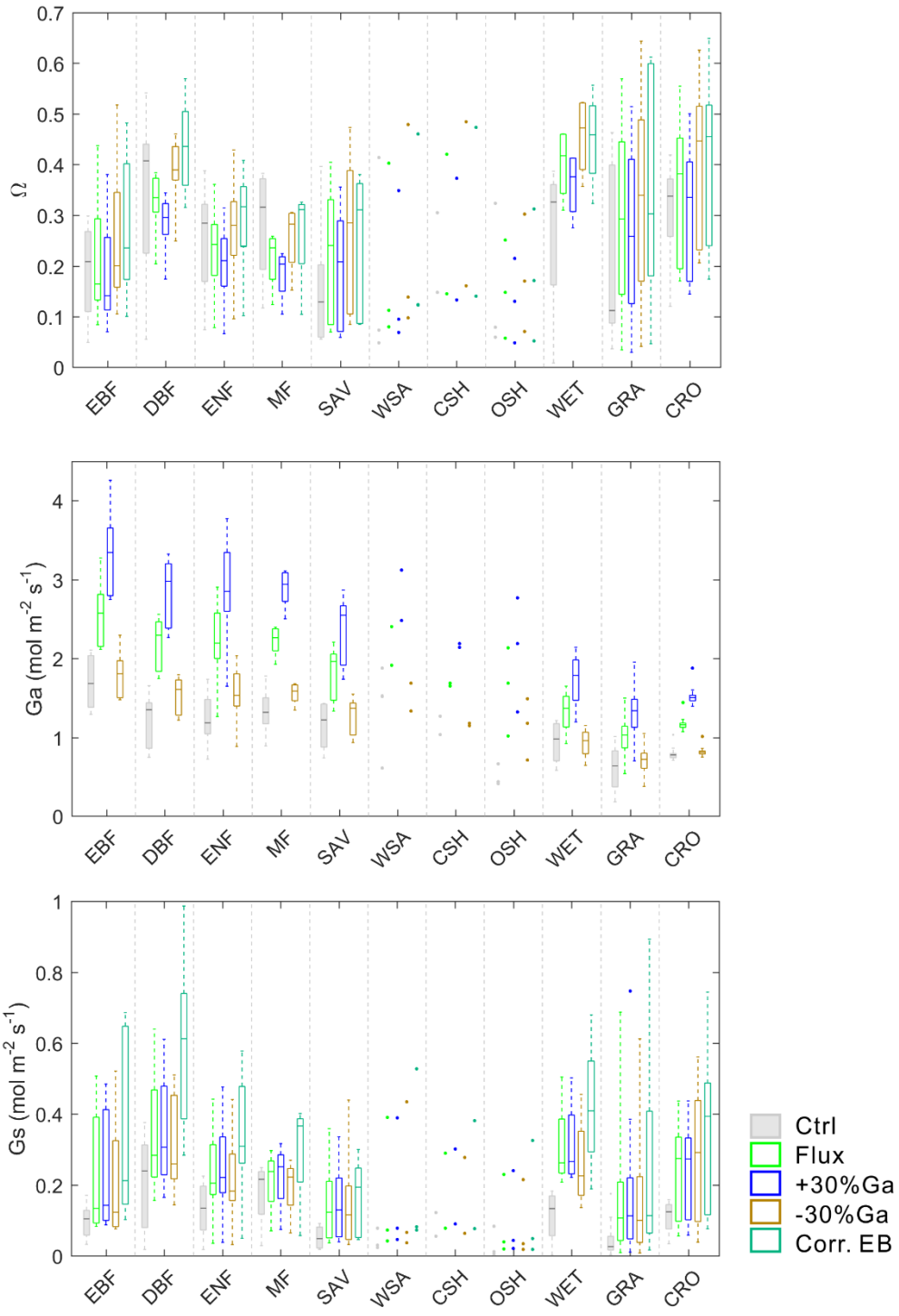

Table S1, site information

Site name	Time	PFT	ORCHIDEE PFT fractions													Canopy Height (m)	Measurement height (m)
			bare soil	TrEBF	TrDBF	TeENF	TeEBF	TeDBF	BoENF	BoDBF	BoDNF	C3Gra	C4Gra	C3Cro	C4Cro		
AR-SLu	2009-2011	MF	0	0	0	0.14	0.14	0.31	0	0	0	0.25	0.16	0	0	4.5	13
AT-Neu	2002-2012	GRA	0	0	0	0	0	0	0	0	0	1	0	0	0	1	3
AU-ASM	2010-2013	ENF	0	0	0	0.65	0	0	0	0	0	0	0.35	0	0	6.5	11.6
AU-Cpr	2010-2014	SAV	0	0	0	0.12	0.12	0.36	0	0	0	0.4	0	0	0	4	20
AU-Cum	2012-2014	EBF	0	0	0	0	0.85	0	0	0	0	0.15	0	0	0	23	30
AU-DaP	2007-2013	GRA	0	0	0.25	0	0	0	0	0	0	0	0.75	0	0	0.3	15
AU-DaS	2008-2014	SAV	0	0	0.6	0	0	0	0	0	0	0	0.4	0	0	16.4	21
AU-Dry	2008-2014	SAV	0	0	0.6	0	0	0	0	0	0	0	0.4	0	0	12.3	15
AU-Emr	2011-2013	GRA	0	0.09	0	0	0	0	0	0	0	0	0.3	0.7	0	2	5.6
AU-Gin	2011-2014	WSA	0	0	0	0	0	0.6	0	0	0	0.4	0	0	0	7	15
AU-GWW	2013-2014	SAV	0	0.04	0.56	0	0	0	0	0	0	0.31	0.09	0	0	18	35

AU-How	2001-2014	WSA	0	0.8	0	0	0	0	0	0	0	0	0.2	0	0	16	23
AU-Rig	2011-2014	GRA	0	0	0	0	0	0	0	0	0	0.9	0.1	0	0	0.4	2.5
AU-Stp	2008-2014	GRA	0	0	0	0	0	0	0	0	0	0	1	0	0	0.5	4.8
AU-TTE	2012-2013	OSH	0.5	0	0.09	0	0	0	0	0	0	0	0.41	0	0	4.85	9.81
AU-Tum	2001-2014	EBF	0	0	0	0	0.95	0.05	0	0	0	0	0	0	0	40	70
AU-Whr	2011-2014	EBF	0	0	0	0	0.8	0.12	0	0	0	0.08	0	0	0	28	32
AU-Ync	2012-2014	GRA	0	0	0	0	0	0	0	0	0	0.85	0.15	0	0	0.5	8
BE-Bra	1996-2014	MF	0	0	0	0.31	0.1	0.44	0	0	0	0.15	0	0	0	21	39
BE-Lon	2004-2014	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2.7
BE-Vie	1996-2014	MF	0	0	0	0.48	0.05	0.32	0	0	0	0.15	0	0	0	35	40
BR-Sa3	2000-2004	EBF	0	0.95	0.05	0	0	0	0	0	0	0	0	0	0	40	64
CA-Qfo	2003-2010	ENF	0	0	0	0	0	0	0.95	0	0	0.05	0	0	0	14	24
CA-SF1	2003-2006	ENF	0	0	0	0	0	0	0.84	0.06	0	0.1	0	0	0	6	12

CA-SF2	2001-2005	ENF	0	0	0	0	0	0	0.85	0	0	0.15	0	0	0	4	10
CA-SF3	2001-2006	OSH	0.2	0	0	0	0	0	0.2	0.2	0	0.4	0	0	0	1	20
CH-Oe1	2002-2008	GRA	0.05	0	0	0	0.04	0.08	0	0	0	0.83	0	0	0	0.5	2
CN-Cha	2003-2005	MF	0	0	0	0	0	0.7	0	0.1	0	0.2	0	0	0	28	40
CN-Cng	2007-2010	GRA	0.1	0	0	0.07	0	0.07	0	0	0	0.3	0.46	0	0	0.75	2
CN-Dan	2004-2005	GRA	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2.1
CN-Du2	2006-2008	GRA	0	0	0	0	0	0	0	0	0	1	0	0	0	0.5	3
CN-HaM	2002-2004	GRA	0	0	0	0	0	0	0	0	0	1	0	0	0	0.3	2,2
CN-Qia	2003-2005	ENF	0	0	0	0.95	0	0	0	0	0	0.05	0	0	0	13	39.6
CZ-wet	2006-2014	WET	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2.7
DE-Geb	2001-2014	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	1	6
DE-Gri	2004-2014	GRA	0	0	0	0	0	0	0	0	0	1	0	0	0	0.7	3
DE-Hai	2000-2012	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	33	43.5

DE-Kli	2004-2014	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	1.5	3.5
DE-Obe	2008-2014	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	19	30
DE-Seh	2007-2010	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	0.8	2
DE-SfN	2012-2014	WET	0.1	0	0	0.55	0	0.05	0	0	0	0.3	0	0	0	2	4.3
DE-Tha	1996-2014	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	26.5	42
DK-Sor	1996-2014	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	25	57
DK-ZaH	2000-2014	GRA	0.05	0	0	0	0	0	0.05	0	0	0.9	0	0	0	0.5	3
FI-Hyy	1996-2014	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	14	23
FI-Sod	2001-2014	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	12.7	23
FR-Gri	2004-2013	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3.17
FR-LBr	1996-2008	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	20	38
FR-Pue	2000-2014	EBF	0	0	0	0	0.88	0	0	0	0	0.12	0	0	0	6.5	11
IT-CA2	2011-2014	CRO	0	0	0	0	0	0	0	0	0	0	0	0.88	0.12	0.3	3.2

IT-CA3	2011-2014	DBF	0	0	0	0	0	0.91	0	0	0	0.09	0	0	0	3.5	7
IT-Cpz	1997-2009	EBF	0	0	0	0	0.88	0	0	0	0	0.12	0	0	0	13	15
IT-Isp	2013-2014	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	19	38
IT-Lav	2003-2014	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	28	33
IT-MBo	2003-2013	GRA	0	0	0	0	0	0	0.05	0.05	0	0.9	0	0	0	0.3	2.5
IT-Noe	2004-2014	CSH	0	0	0	0.47	0.1	0.16	0	0	0	0.27	0	0	0	1.2	3
IT-PT1	2002-2004	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	26	30
IT-Ren	1998-2013	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	28	40
IT-Ro2	2002-2012	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	15	20
IT-SR2	2013-2014	ENF	0	0	0	0.85	0	0.05	0	0	0	0.1	0	0	0	19	23.5
IT-SRo	1999-2012	ENF	0	0	0	0.85	0	0.05	0	0	0	0.1	0	0	0	16	23.5
NL-Hor	2004-2011	GRA	0	0	0	0	0	0	0	0	0	0.9	0.1	0	0	1	4.7
NL-Loo	1996-2013	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	15.5	27

RU-Fyo	1998-2014	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	21	48
SD-Dem	2005-2009	SAV	0	0	0.07	0	0	0	0	0	0	0	0.93	0	0	1.5	2.5
US-AR1	2009-2012	GRA	0	0	0	0	0	0	0	0	0	0.63	0.37	0	0	1	2.84
US-AR2	2009-2012	GRA	0	0	0	0	0	0	0	0	0	0.63	0.37	0	0	1	2.95
US-ARM	2003-2012	CRO	0	0	0	0	0	0	0	0	0	0	0	0.6	0.4	0.5	60
US-Blo	1997-2007	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	4.7	12.5
US-Cop	2001-2007	GRA	0	0	0	0	0	0	0	0	0	0.75	0.25	0	0	0.5	1.85
US-GLE	2004-2014	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	10	23
US-KS2	2003-2006	CSH	0	0	0	0	0.3	0.4	0	0	0	0.16	0.14	0	0	2	3.5
US-Los	2000-2014	WET	0	0	0	0	0	0	0.15	0.25	0	0.6	0	0	0	2	10.2
US-Me2	2002-2014	ENF	0	0	0	0.85	0.05	0	0	0	0	0.1	0	0	0	16	29
US-MMS	1999-2014	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	27	48
US-Ne1	2001-2013	CRO	0	0	0	0	0	0	0	0	0	0	0	0	1	3	6

US-Ne3	2001-2013	CRO	0	0	0	0	0	0	0	0	0	0	0	0	1	2.5	6
US-NR1	1998-2014	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	12	26
US-Prr	2010-2013	ENF	0	0	0	0	0	0	0.9	0	0	0.1	0	0	0	7	16
US-SRG	2008-2014	GRA	0	0	0	0.02	0.02	0.04	0	0	0	0.15	0.75	0	0	1	3.25
US-Syv	2001-2014	MF	0	0	0	0	0	0	0.45	0.45	0	0.1	0	0	0	27	36
US-Ton	2001-2014	WSA	0	0	0	0.15	0.15	0.25	0	0	0	0.45	0	0	0	7.1	23
US-Tw4	2013-2014	WET	0.1	0	0	0	0	0	0	0	0	0.9	0	0	0	0.5	3
US-Twt	2009-2014	CRO	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	3.25
US-Var	2000-2014	GRA	0	0	0	0	0	0.05	0	0	0	0.95	0	0	0	0.55	3
US-WCr	1999-2014	DBF	0	0	0	0	0	0.9	0	0	0	0.1	0	0	0	24	40
US-Whs	2007-2014	OSH	0.2	0	0	0	0	0.1	0	0	0	0	0.7	0	0	0.5	4
US-Wkg	2004-2014	GRA	0	0	0	0	0	0	0	0	0	0.6	0.4	0	0	1	6.4
ZA-Kru	2000-2010	SAV	0	0	0	0.14	0.14	0.32	0	0	0	0.12	0.28	0	0	12	16

ZM-Mon	2000-2009	DBF	0	0	0	0	0	0.9	0	0	0	0	0.1	0	0	12	33

* the PFT acronyms of ORCHIDEE PFTs are:

TrEBF Tropical broad-leaved evergreen forests

TrDBF Tropical broad-leaved raingreen forests

TeENF Temperate needleleaf evergreen forests

TeEBF Temperate broad-leaved evergreen forests

TeDBF Temperate broad-leaved summergreen forests

BoENF Boreal needleleaf evergreen forests

BoDBF Boreal broad-leaved summergreen forests

BoDNF Boreal needleleaf summergreen forests

C3Gra C3 grasslands

C4Gra C4 grasslands

C3Cro C3 croplands

C4Cro C4 croplands

Table S2. Mean g_1 values for plant functional types from (*Lin et al.*, 2015) and their corresponding empirical parameters a_1 and b_1 calibrated for this study using the method described in this Supplementary.

PFTs in ORCHIDEE	a_1 (default ORCHIDEE)	b_1 (default ORCHIDEE)	PFTs from Lin et al., (2015)	g_1 from Lin et al., (2015)	a_1 (constrained by g_1)	b_1 (constrained by g_1)
TrEBF	0.85	0.14	Tropical rain forest tree	3.77	0.94	0.048
TrDBF	0.85	0.14	Deciduous Savanna tree	2.98	0.92	0.053
TeENF	0.85	0.14	Evergreen gymnosperm tree	2.35	0.90	0.056
TeEBF	0.85	0.14	Evergreen angiosperm tree	3.37	0.93	0.051
TeDBF	0.85	0.14	Deciduous angiosperm tree	4.64	0.95	0.044
BoENF	0.85	0.14	Evergreen gymnosperm tree	2.35	0.90	0.056
BoDBF	0.85	0.14	Deciduous angiosperm tree	4.64	0.95	0.044
BoDNF	0.85	0.14	Evergreen gymnosperm tree [1]	2.35	0.90	0.056
C3Gra	0.85	0.14	C3 grass	4.50	0.95	0.045
C4Gra	0.72	0.20	C4 grass	1.62	0.85	0.058
C3Cro	0.85	0.14	C3 crops	5.79	0.96	0.039
C4Cro	0.72	0.20	C4 crops	4.22	0.95	0.046

[1] BoDNF is absent in *Lin et al.* (2015) dataset, due to the similarity between BoDNF and BoENF during the growing season, we used the same value here

Table S3. The Default canopy height in ORCHIDEE

PFTs in ORCHIDEE	Default canopy height (m)
TrEBF	30
TrDBF	30
TeENF	20
TeEBF	20
TeDBF	20
BoENF	15
BoDBF	15
BoDNF	15
C3Gra	0.5
C4Gra	0.6
C3Cro	1
C4Cro	1