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Evaluating the performance of land surface model ORCHIDEE-CAN v1.0 on water and energy flux estimation with a single- and multi-layer energy budget scheme

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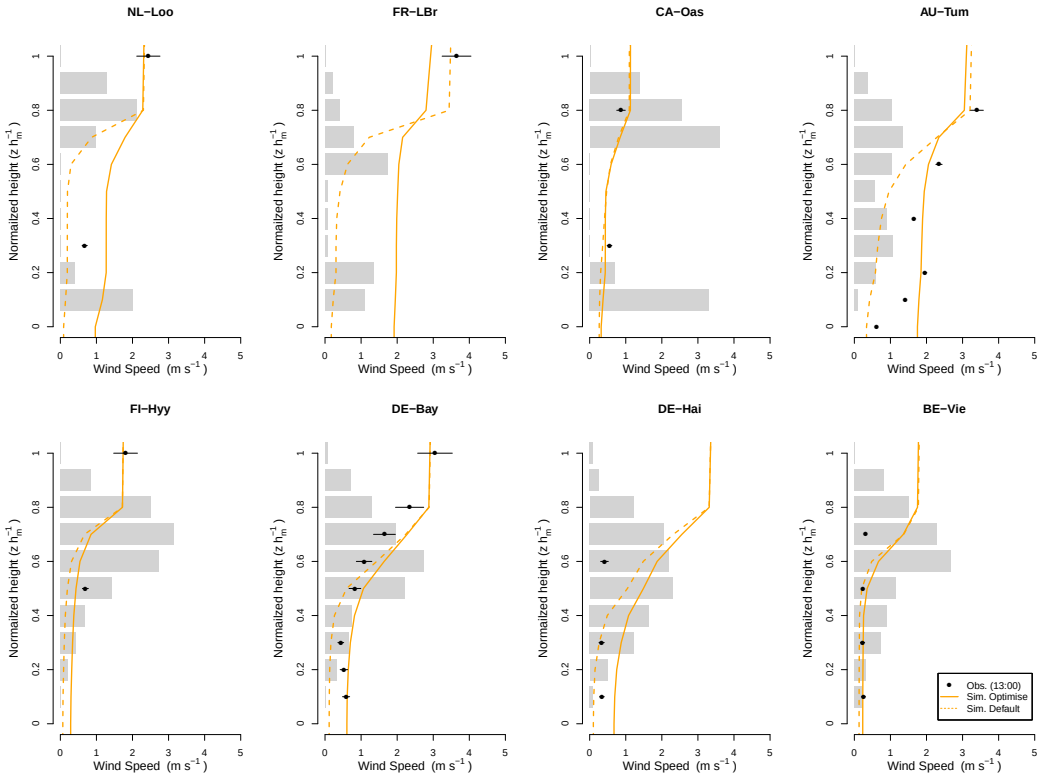

Figure S1. Model simulation and observation of the wind speed profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimized parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

Table S1. Description of the experimental design. The model was forced either by the site-level observations (SITE) or the CRU-NCEP re-analysis (CRU) and was run with the single-layer energy budget scheme (SINGLE) or the multi-layer energy budget scheme (MULTI). The model could be forced to follow the observed LAI profiles (IMPOSE) or made use of the internal calculation of the seasonal dynamics and vertical profile of LAI (SIM). EXP denotes the experiment name, PERIOD refers to the periods for which the simulations were run as defined in Table 3.

EXP	FORCING		ENERGY BUDGET		LAI PROFILE		PERIOD
	SITE	CRU	SINGLE	MULTI	IMPOSE	SIM	
SPINUP		+	+			+	20yrs
optimizE	+		+		+		I & II
EXP1	+		+		+		III
EXP2	+		+		+		IV
EXP3	+			+	+		III
EXP4	+			+	+		IV

*

Table S2. Optimized parameter values per site. The uncertainties (1 standard deviation) were derived from the sensitivity analysis for the soil water content at the end of the spin-up.

Site Code	**FI-Hyy**	**FR-LBr**	**NL-Loo**	**DE-Bay**	**CA-Oas**	**AU-Tum**	**DE-Hai**	**BE-Vie**
a_3	0.420(±0.0038)	0.300(±0.0027)	0.302(±0.0027)	0.387(±0.0035)	0.234(±0.0021)	0.360(±0.0032)	0.301(±0.0027)	0.341(±0.0031)
a_4	-0.374(±0.0041)	-0.098(±0.0011)	-0.111(±0.0012)	-0.306(±0.0034)	-0.051(±0.0006)	-0.081(±0.0009)	-0.400(±0.0044)	-0.223(±0.0025)
a_5	0.050(±0.0010)	0.050(±0.0010)	0.085(±0.0017)	0.006(±0.0001)	0.079(±0.0016)	0.028(±0.0006)	0.059(±0.0012)	0.086(±0.0017)
a_6	16.82(±0.0841)	11.52(±0.0576)	11.29(±0.0565)	19.21(±0.0961)	10.56(±0.0528)	20.10(±0.1005)	10.01(±0.0501)	11.00(±0.0550)
a_7	0.06(±0.0005)	0.32(±0.0026)	0.18(±0.0014)	0.11(±0.0009)	0.21(±0.0017)	0.40(±0.0032)	0.13(±0.0010)	0.05(±0.0004)
a_8	4.57(±0.0914)	4.82(±0.0964)	1.71(±0.0342)	5.10(±0.1200)	6.53(±0.1360)	1.50(±0.0300)	5.20(±0.1400)	4.70(±0.0940)
a_9	0.52(±0.0026)	0.45(±0.0015)	0.77(±0.0022)	0.56(±0.0015)	0.57(±0.0029)	0.62(±0.0031)	0.46(±0.0023)	0.53(±0.0027)
a_{10}	0.99(±0.0198)	0.95(±0.0180)	0.52(±0.0102)	0.93(±0.0186)	0.95(±0.0190)	1.60(±0.0320)	0.97(±0.0194)	0.95(±0.0190)
W_{br}	0.81(±0.0353)	2.63(±0.1147)	1.83(±0.0798)	7.57(±0.3301)	3.20(±0.1395)	0.86(±0.0375)	7.56(±0.3296)	4.53(±0.1975)
W_{sr}	2.97(±0.0624)	1.88±0.0395	5.53(±0.1161)	2.87(±0.0603)	6.70(±0.1407)	2.43±0.0510	4.27(±0.0897)	4.35(±0.0914)

Table S3. Calibration results during observation Period I and II for each site.

		Period I		Period II	
Site Code	optimized variable	RMSE prior(default)	RMSE optimized	RMSE prior(default)	RMSE optimized
AU-Tum	R_n	51.4	51.9		
	LE	86.6	38.9	39.5	42.4
	H	150.9	33.1	46.3	36.4
	U	0.15	0.07		
	T_a	0.48	0.35		
	q_a	0.00030	0.00027		
BE-Vie	R_n	32.9	39.6		
	LE	102.6	38.1	125.8	23.5
	H	97.3	44.8	127.7	31.3
	U	0.64	0.64		
	T_a	0.61	0.86		
	q_a	0.00087	0.00083		
CA-Oas	R_n	35.1	34.1		
	LE	54.0	34.7	150.9	62.4
	H	73.9	50.2	155.3	72.2
	U	0.25	0.21		
	T_a	1.27	1.24		
	q_a	n.a.	n.a		
DE-Bay	R_n	33.3	33.3		
	LE	76.3	74.7	128.1	23.4
	H	60.7	30.2	136.6	34.2
	U	0.62	0.21		
	T_a	0.82	0.64		
	q_a	n.a.	n.a		
DE-Hai	R_n	21.0	24.7		
	LE	138.6	35.7	87.4	32.3
	H	148.9	48.9	88.2	43.5
	U	2.05	1.21		
	T_a	0.78	0.79		
	q_a	n.a.	n.a		

Table S3. Continuation of Table **??**

		Period I		Period II	
Site Code	optimize variable	RMSE prior(default)	RMSE optimized	RMSE prior(default)	RMSE optimized
FI-Hyy	R_n	33.5	33.0		
	LE	157.9	49.3	44.5	21.2
	H	155.5	52.5	46.9	32.3
	U	0.23	0.15		
	T_a	1.15	1.14		
	q_a	0.00024	0.00015		
FR-LBr	R_n	27.4	25.6		
	LE	89.4	49.5	44.5	40.4
	H	73.4	47.3	51.7	32.8
	U	0.17	0.15		
	T_a	1.46	1.46		
	q_a	0.00037	0.00038		
NL-Loo	R_n	33.6	33.4		
	LE	71.2	47.9	63.2	22.1
	H	122.4	56.9	63.9	33.3
	U	0.88	0.75		
	T_a	0.81	0.78		
	q_a	0.00072	0.00067		
All Sites	R_n	33.5	34.5		
	LE	91.2	46.1	85.5	38.2
	H	123.2	50.3	89.6	40.4
	U	0.62	0.42		
	T_a	0.92	0.93		
	q_a	0.00047	0.00043		

Table S4. Evaluation of the model performance, Taylor score (S_T), correlation coefficient (R) and root mean square error (RMSE) for four experiments and changes in performance.

Experiment	**EXP1**	**EXP2**	**|EXP1-EXP2|**	**EXP3**	**EXP4**	**|EXP3-EXP4|**
Rn						
S_T $(0-1)$	0.961	0.931	0.030	0.893	0.924	0.031
R $(0-1)$	0.986	0.874		0.763	0.903	
RMSE (Wm^{-2})	33.21	87.30		113.1	64.31	
H						
S_T $(0-1)$	0.863	0.828	0.035	0.810	0.865	0.054
R $(0-1)$	0.777	0.689		0.774	0.788	
RMSE (Wm^{-2})	59.64	71.51		45.88	42.15	
LE						
S_T $(0-1)$	0.822	0.778	0.044	0.786	0.745	0.041
R $(0-1)$	0.804	0.710		0.649	0.645	
RMSE (Wm^{-2})	48.06	56.44		51.64	41.01	
G						
S_T $(0-1)$	0.234	0.275	0.041	0.410	0.454	0.044
R $(0-1)$	0.544	0.451		0.424	0.507	
RMSE (Wm^{-2})	23.64	24.83		20.04	19.14	

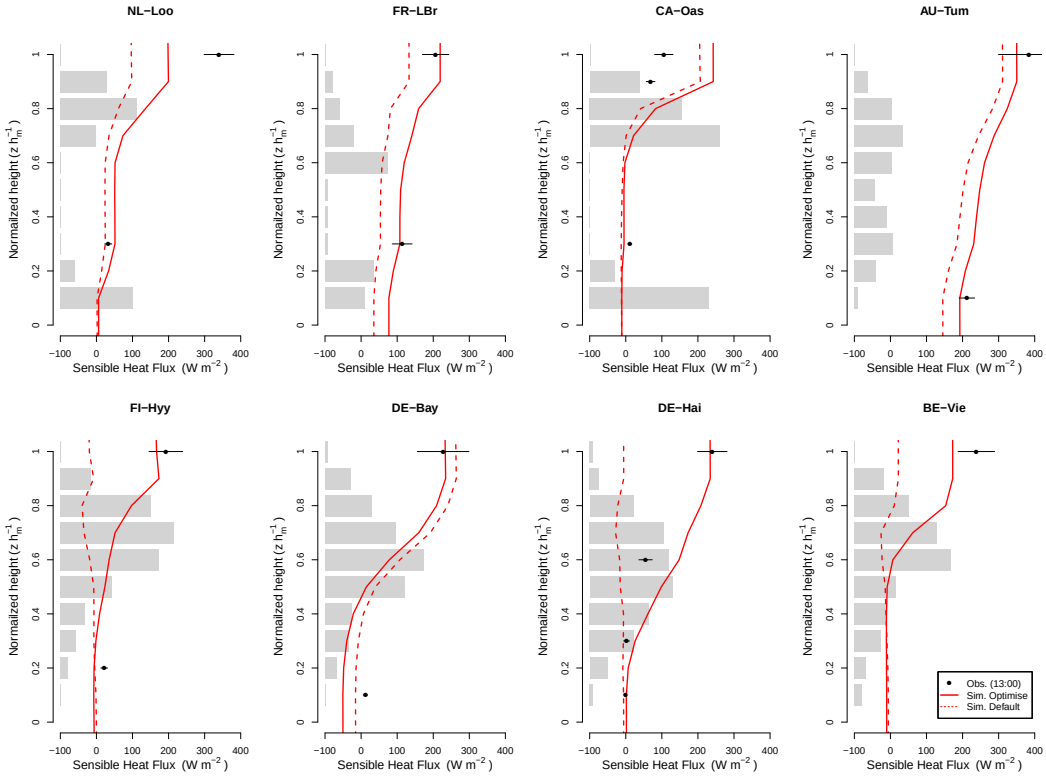

Figure S2. Model simulation and observation of the sensible heat flux profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimized parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

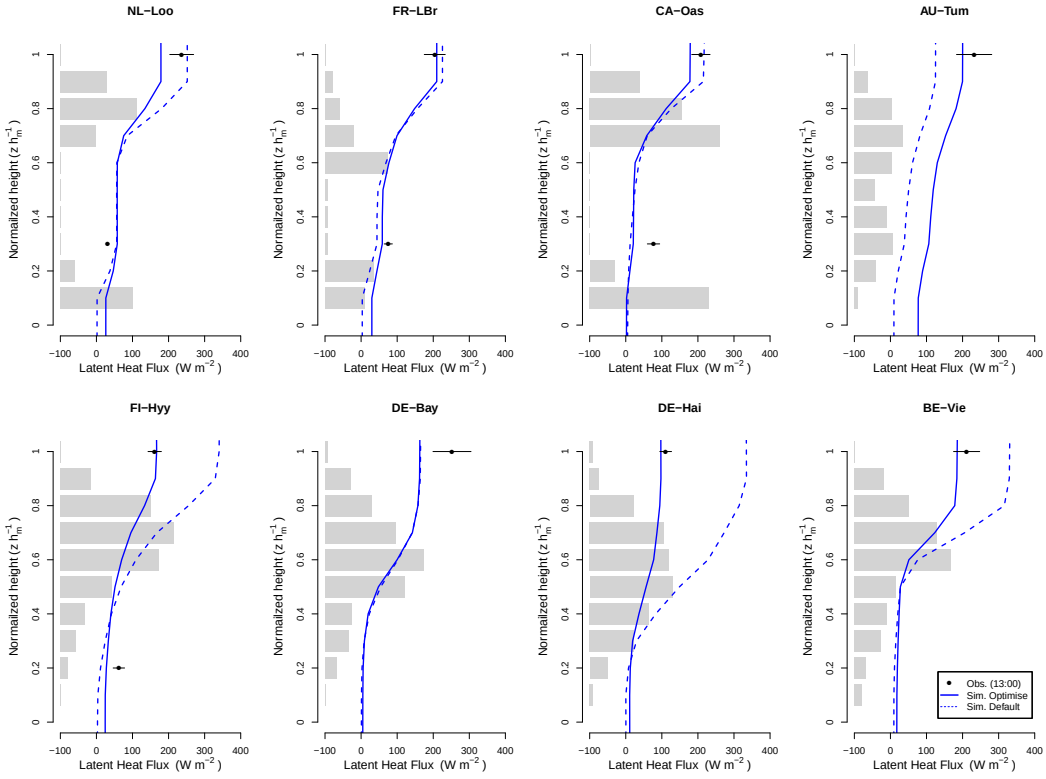

Figure S3. Model simulation and observation of the latent heat flux profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimize parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

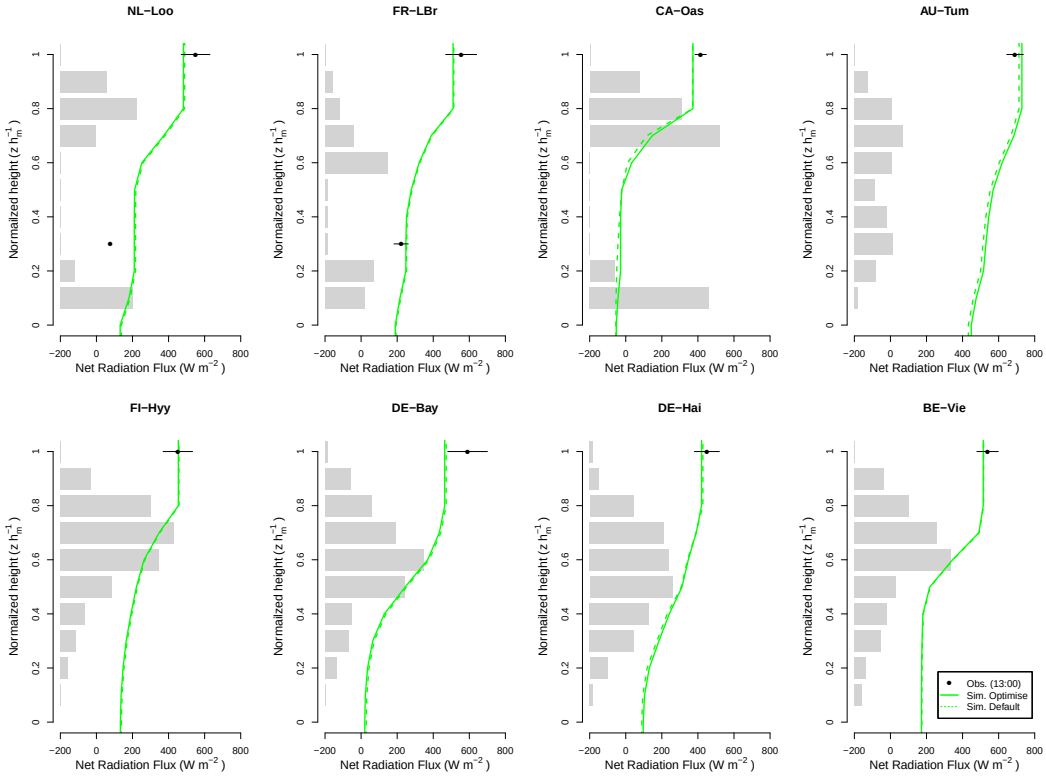

Figure S4. Model simulation and observation of the net radiation profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimized parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

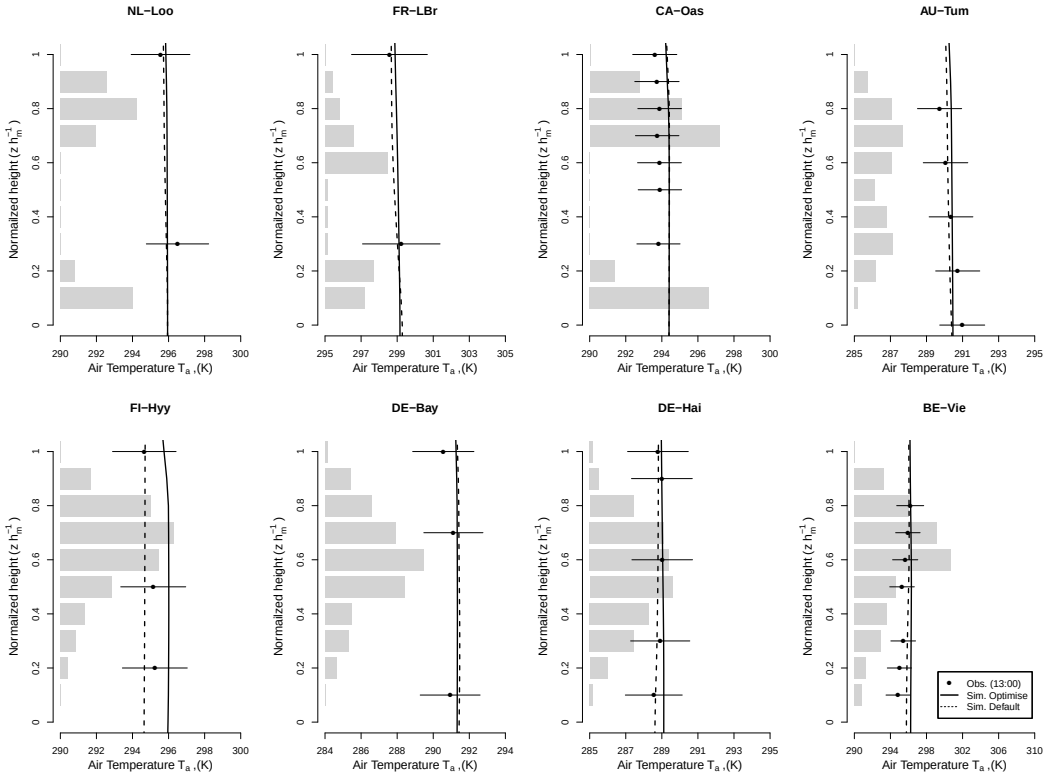

Figure S5. Model simulation and observation of the air temperature profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimized parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

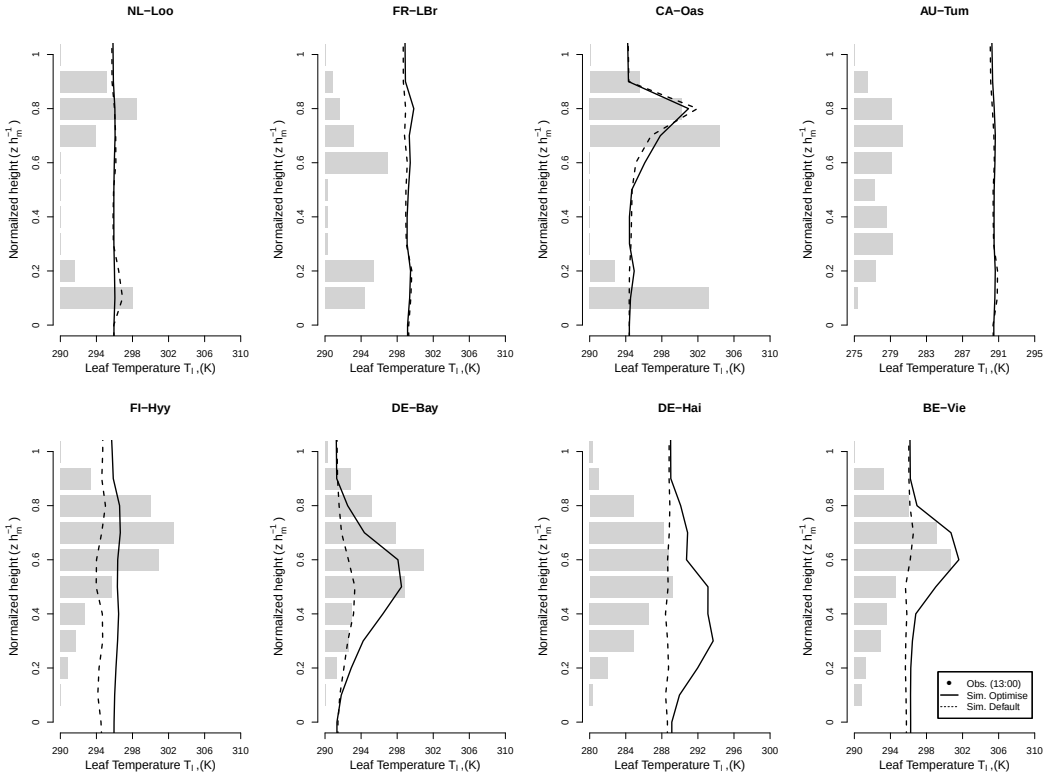

Figure S6. Model simulation and observation of the leaf temperature profile at eight forest sites during the short-term campaign (Period I). All the dashed lines indicate the prior simulation with default parameter values and the solid lines present the optimized simulation with optimized parameter values. The filled circles are the observation means and the bars are stand deviations over the simulation period at 13:00. The gray bars in the background indicate the measured maximum LAI at each level in the reference year.

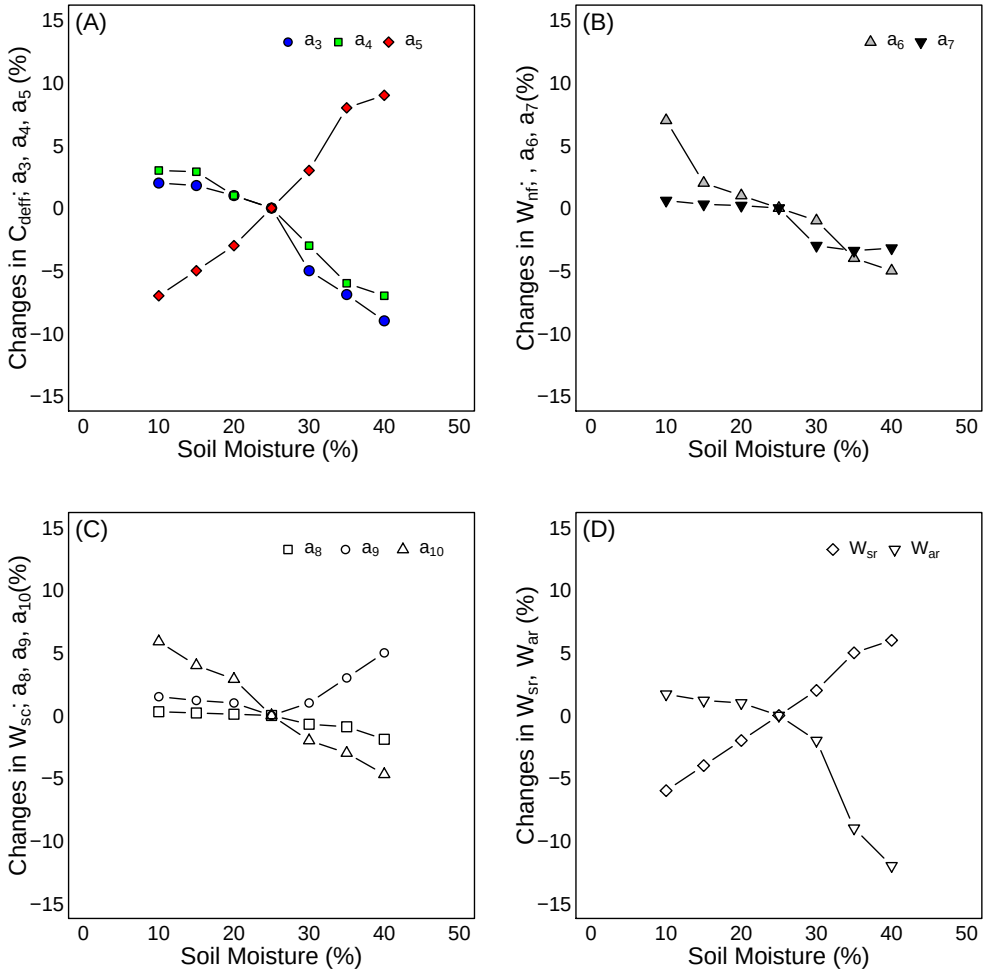

Figure S7. Sensitivity test of using default k_{surf} value with different initial soil moisture conditions to determine optimized parameter values for short term period at FR-LBr site. (A) parameters from a_3 to a_5 to determine the effective surface drag coefficient, C_{Deff} (B) parameters a_6 and a_7 to determine the weighting factor for eddy diffusivity, W_{nf} (C) parameter from a_8 to a_{10} to determine the weighting factor for surface-air interface conductance, W_{sf} (D) weighting factor for stomatal resistance W_{sr} and boundary layer resistance W_{br}, respectively.