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Intercomparison of biogenic CO_2 flux models in four urban parks in the city of Zurich

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Supplementary material

Table S1. Parameters used by diFUME model in the Equations of Table A1, along with their units, a short description, and the references used for determining their value. diFUME does not discriminate between different vegetation types, using approximate values for temperate deciduous broadleaved trees and grasses (Stagakis et al., 2023).

Parameter	Value	Units	Description	Reference
A_{max}	15	μmol CO_2 m^{-2} s^{-1}	maximum leaf gross photosynthetic rate	Stagakis et al., 2023; Larcher, 2003
a	0.045	mol CO_2 mol^{-1} PAR	quantum yield for CO_2 assimilation	Rogers et al., 2017
a_1	25	N/A	empirical coefficient in Leuning (1995) model	Leuning, 1995
b	0.65	N/A	empirical coefficient in β-factor formula	this study
b_1	5	N/A	empirical coefficient	Stagakis et al., 2023
D_o	0.3	kPa	empirically determined coefficient for the VPD scalar inside Leuning (1995) model	this study
D_{sc}	1	N/A	daylight scalar for dark respiration inhibition during day (1: no inhibition)	this study
E_0	487.75	K	temperature sensitivity parameter for soil respiration	this study
g_o	0.01	mol CO_2 m^{-2} s^{-1}	residual stomatal conductance for CO2 (g_s when A_{net} = 0, PAR = 0).	Leuning, 1995
Q_{10}	1.85	N/A	temperature sensitivity of leaf respiration	Heskel et al., 2016
$R_{l,ref}$	1.53	μmol CO_2 m^{-2} s^{-1}	reference leaf respiration at T_{air} = 25 °C	Heskel et al., 2016
$R_{S,ref}$	2.49	μmol CO_2 m^{-2} s^{-1}	reference soil respiration at T_{soil} = 10 °C	this study
T_{air}	input	°C	air temperature	-
T_{opt}	23	°C	optimum air temperature for gross photosynthesis	Larcher, 2003
T_0	-46	°C	low-temperature limit for soil respiration	Lloyd and Taylor, 1994
$T_{ref,S}$	10	°C	reference soil temperature for soil respiration	Lloyd and Taylor, 1994
$T_{ref,l}$	25	°C	reference air temperature for leaf respiration	Heskel et al., 2016
T_{soil}	input	°C	soil temperature	-
VPD	input	kPa	vapour pressure deficit	-
W	10	°C	width of the bell-shape curve at $f(T_{air})$ = 0.5	Larcher, 2003
θ	input	m^3 m^{-3}	soil volumetric water content	-
θ_{ref}	0.4	m^3 m^{-3}	saturated soil volumetric water content	Stagakis et al., 2023
θ_g	0.1	m^3 m^{-3}	minimum soil volumetric water content, limit to stomatal conductance	this study
θ_0	0.04	m^3 m^{-3}	minimum soil volumetric water content, limit to soil respiration	Stagakis et al., 2023
λ_{soil}	input	N/A	land cover fraction covered by soil or grass	-

Table S2. Parameters used by JSBACH in the equations in Table A1, along with their units, a short description, and the references used for determining their value. For additional details on the model equations see Reick et al. (2021). Other parameters that have been altered in this study are also listed.

Parameter	Trees	Lawn	Units	Description	Reference
A_{stress}	simulated		μmol(CO_2) m^{-2} (leaf) s^{-1}	Carbon assimilation under water stress	-
CC	1.25	1.25	N/A	Relative cost to produce one carbon	Ryan, 1991
C_h	simulated		μmol(CO_2) m^{-2}	Humus carbon pool	-
$F_{grazing}$	simulated		μmol(CO_2) m^{-2} s^{-1}	Grazing losses of the green C pool to herbivores	-
F_{soil}	simulated		μmol(CO_2) m^{-2} s^{-1}	CO_2 flux from litter pools to the atmosphere	-
f_{faeces}	0.3	0.3	N/A	Fraction of carbon from herbivore faeces that goes into the green litter pool	Halliday, 2003
f_{ws}	simulated		N/A	Factor that depends on soil moisture in the root zone and specific humidity	-
f_{leaf}	0.4	0.4	N/A	A fixed fraction of canopy maintenance respiration that makes up the dark respiration	Knorr, 2000
$g_L^{H_2O}$	simulated		m s^{-1}	Canopy conductance in absence of water stress	-
$g_{L,stress}^{H_2O}$	simulated		m s^{-1}	Canopy conductance taking into account water stress	-
$J_{C,stress}$	simulated		μmol(CO_2) m^{-2} (leaf) s^{-1}	Actual carboxylation rate under water stress	-
$J_{E,stress}$	simulated		μmol(CO_2) m^{-2} (leaf) s^{-1}	Actual electron transport rate under water stress	-
k	0.1	0.09	N/A	LAI growth rate during growth phase	this study
k_h	simulated		s^{-1}	Carbon loss rate from humus pool	-
LAI_{max}	3.6–4.1	3.0	m^2 m^{-2}	Maximum leaf area index	this study
p	veg: 0.004 rest: 0.1	growth: 0.1 dry: 0.015	N/A	LAI shedding rate (trees: vegetative and rest phase; grass: growth and dry season)	this study
R_g	simulated		μmol(CO_2) m^{-2} s^{-1}	Growth respiration	-
R_h	simulated		μmol(CO_2) m^{-2} s^{-1}	Heterotrophic respiration	-
R_m	simulated		μmol(CO_2) m^{-2} s^{-1}	Maintenance respiration	-
r_d	0.605	0.8602	μmol(CO_2) m^{-2} (leaf) s^{-1}	Dark respiration at 25 °C, fraction of V_{max}	this study
Additional parameters that were altered in this study					
J_{max}	104.5	148.6	μmol(CO_2) m^{-2} (leaf) s^{-1}	Maximum electron transport rate at 25 °C	this study
T_{alt}	4.0–4.5		°C	Alternation temperature	this study
θ_{cap}	0.32–0.39	0.32–0.34	m m^{-1}	Volumetric soil field capacity	this study
θ_{pwp}	0.13–0.21	0.135–0.165	m m^{-1}	Volumetric wilting point	this study

V_{max}	55.0	78.2	$\mu mol(CO_2)\ m^{-2}$ (leaf) s^{-1}	Maximum carboxylation rate at 25 °C	this study
z_{root}	0.5	0.12	m	Root depth	this study

Table S3. Parameters used by SUEWS model in the Equations of Table A1, along with their units, a short description, and the references used for determining their value.

Parameter	Trees	Lawn	Units	Description	Reference
fr_i	0.21	0.18	N/A	Fraction of each vegetation type i	this study
$F_{pho,max,i}$	8.3	8.92	$\mu mol\ m^{-2}\ s^{-1}$	Maximum potential photosynthesis	Havu et al., 2024
$LAI_{max,i}$	4.8	3	$m^2\ m^{-2}$	Full leaf-on summertime value	
$LAI_{min,i}$	0.66	1.6	$m^2\ m^{-2}$	Leaf-off wintertime value	
T_{air}	simulated		°C	Air temperature	Järvi et al., 2011
Δq	input		g/kg	Specific humidity	
$\Delta\theta$	simulated		mm	Soil moisture deficit	
$K_{\downarrow}$	input		$W\ m^{-2}$	Incoming shortwave radiation	
T_L	-10	-10	°C	Lower air temperature limit	
T_H	55	55	°C	Upper air temperature limit	
G_5	30	30	°C	Parameter related to temperature dependence	Havu et al., 2024
G_3	0.66	0.538	N/A	Parameter related to VPD dependence	
G_4	0.89	0.87	N/A	Parameter related to VPD dependence	
G_6	0.36	0.55	mm^{-1}	Parameter related to soil moisture dependence	
G_2	477	263.5	$W\ m^{-2}$	Parameter related to $K_{\downarrow}$ dependence	
$\Delta\theta_{WP}$	132.5	143	mm	Wilting point deficit	
$K_{\downarrow max}$	1200	1200	$W\ m^{-2}$	Maximum incoming shortwave radiation	Järvi et al., 2011
a_i	0.78	1.7	N/A	Empirical soil and vegetation respiration coefficient	Havu et al., 2024
b_i	0.08	0.06	N/A	Empirical soil and vegetation respiration coefficient	
$\omega_{1,GDD,i}$	0.04	0.04	N/A	Parameter for LAI calculation	Järvi et al., 2014
$\omega_{2,GDD,i}$	0.0005	0.0005	N/A	Parameter for LAI calculation	Järvi et al., 2011
$\omega_{1,SDD,i}$	-1.5	-1.5	N/A	Parameter for LAI calculation	Järvi et al., 2014
$\omega_{1,SDD,i}$	0.0025	0.0025	N/A	Parameter for LAI calculation	Järvi et al., 2014, modified
GDD	300	300	days	The growing degree days (GDD) needed for full capacity of the leaf area index	Järvi et al., 2011
SDD	-300	-300	days	The senescence degree days (SDD) needed to initiate leaf off	Järvi et al., 2011, modified
$T_{base,GDD}$	5	5	°C	Base Temperature for initiating growing degree days (GDD) for leaf growth	Järvi et al., 2011
$T_{base,SDD}$	10	10	°C	Base temperature for initiating senescence degree days (SDD) for leaf off	

Table S4 Parameters used by VPRM model in the Equations of Table A1, along with their units, a short description, and the references used for determining their value.

Parameter	Trees	Lawn	Units	Description	Reference
λ	-0.16	-0.13	μmol CO_2 m^{-2} s^{-1}	light use efficiency	Glauch et al., 2025
PAR	input		μmol m^{-2} s^{-1}	photosynthetically active radiation	
PAR_0	356.99	545.61	μmol m^{-2} s^{-1}	half-saturation value	
α	0.22	0.40	μmol CO_2 m^{-2} s^{-1} /^{0}C	empirical coefficient	
β	1.09	0.42	μmol CO_2 m^{-2} s^{-1}	empirical coefficient	
T	input		°C	air temperature	
T_{max}	40	40	°C	maximum temperature for photosynthesis	
T_{min}	0	2	°C	minimum temperature for photosynthesis	
T_{opt}	20	18	°C	optimal temperature for photosynthesis	
T_{low}	0	0	°C	to account for the persistence of soil respiration in winter	

References

Glauch, T., Marshall, J., Gerbig, C., Botía, S., Gałkowski, M., Vardag, S. N., and Butz, A.: *pyVPRM*: A next-generation Vegetation Photosynthesis and Respiration Model for the post-MODIS era, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3692, 2025.

Halliday, J. C., Tate, K. R., McMurtrie, R. E. and Scott, N. A., Mechanisms for changes in soil carbon storage with pasture to *Pinus radiata* land-use change. Global Change Biology, 9, 1294, https://doi.org/10.1046/j.1365-2486.2003.00659.x, 2003.

Havu, M., Kulmala, L., Lee, H. S., Saranko, O., Soininen, J., Ahongshangbam, J., and Järvi, L.: CO2 uptake of urban vegetation in a warming Nordic city, Urban For. Urban Green., 94, https://doi.org/10.1016/j.ufug.2024.128261, 2024.

Heskel, M. A., O'Sullivan, O. S., Reich, P. B., Tjoelker, M. G., Weerasinghe, L. K., Penillard, A., Egerton, J. J. G., Creek, D., Bloomfield, K. J., Xiang, J., Sinca, F., Stangl, Z. R., Martinez-De La Torre, A., Griffin, K. L., Huntingford, C., Hurry, V., Meir, P., Turnbull, M. H., and Atkin, O. K.: Convergence in the temperature response of leaf respiration across biomes and plant functional types, Proc. Natl. Acad. Sci. U. S. A., 113, 3832–3837, https://doi.org/10.1073/pnas.1520282113, 2016.

Järvi, L., Grimmond, C. S. B., and Christen, A.: The Surface Urban Energy and Water Balance Scheme (SUEWS): Evaluation in Los Angeles and Vancouver, J. Hydrol., 411, 219–237, https://doi.org/10.1016/j.jhydrol.2011.10.001, 2011.

Järvi, L., Grimmond, C. S. B., Taka, M., Nordbo, A., Setälä, H., and Strachan, I. B.: Development of the Surface Urban Energy and Water Balance Scheme (SUEWS) for cold climate cities, Geosci. Model Dev., 7, https://doi.org/10.5194/gmd-7-1691-2014, 2014.

June, T., Evans, J. R., and Farquhar, G. D.: A simple new equation for the reversible temperature dependence of photosynthetic electron transport: A study on soybean leaf, Funct. Plant Biol., 31, 275–283, https://doi.org/10.1071/FP03250, 2004.

Knorr, W., Annual and interannual CO_2 exchanges of the terrestrial biosphere: process-based simulations and uncertainties. Global Ecology and Biogeography, 9, 225, https://doi.org/10.1046/j.1365-2699.2000.00159.x, 2000.

Larcher, W., 2003. Physiological Plant Ecology: Ecophysiology and Stress Physiology of Functional Groups, 4th ed. Springer, Berlin.

Leuning, R.: A critical appraisal of a combined stomatal-photosynthesis model for C3 plants, Plant. Cell Environ., 18, 339–355, https://doi.org/10.1111/j.1365-3040.1995.tb00370.x, 1995.

Lloyd, J. and Taylor, J. A.: On the Temperature Dependence of Soil Respiration, Funct. Ecol., 8, 315, https://doi.org/10.2307/2389824, 1994.

Reick, C. H., Gayler, V., Goll, D., Hagemann, S., Heidkamp, M., Nabel, J. E. M. S., Raddatz, T., Roeckner, E., Schnur, R. and Wilkenskjeld, S., JSBACH 3 - The land component of the MPI Earth System Model: documentation of version 3.2. Berichte zur Erdsystemforschung,240. doi:10.17617/2.3279802, 2021.

Rogers, A., Medlyn, B. E., Dukes, J. S., Bonan, G., von Caemmerer, S., Dietze, M. C., Kattge, J., Leakey, A. D. B., Mercado, L. M., Niinemets, Ü., Prentice, I. C., Serbin, S. P., Sitch, S., Way, D. A., and Zaehle, S.: A roadmap for improving the representation of photosynthesis in Earth system models, https://doi.org/10.1111/nph.14283, 2017.

Ryan, M. G., Effects of Climate Change on Plant Respiration. Ecological Applications, 1, 157. https://doi.org/10.2307/1941808, 1991.

Stagakis, S., Feigenwinter, C., Vogt, R., and Kalberer, M.: A high-resolution monitoring approach of urban CO2 fluxes. Part 1 - bottom-up model development, Sci. Total Environ., 858, 160216, https://doi.org/10.1016/j.scitotenv.2022.160216, 2023.