Supplementary to "**Water level variation at a beaver pond significantly impacts net CO_2 uptake of a continental bog**"

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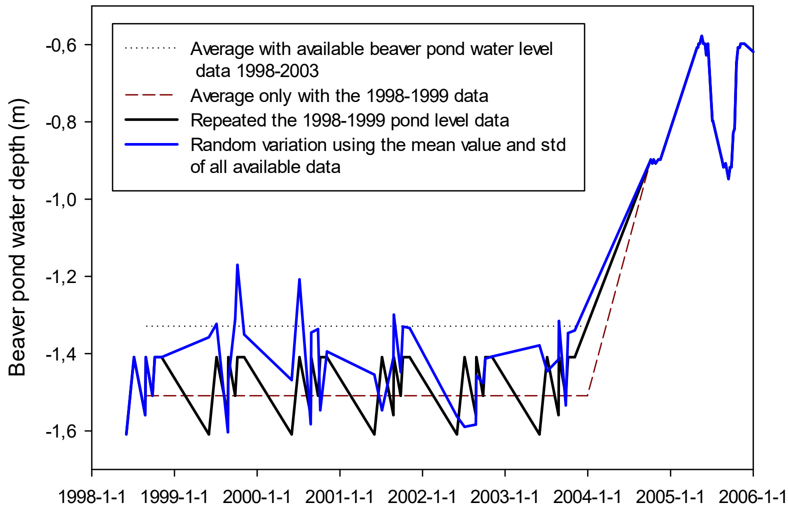
A. Different assumptions to estimate data gaps of the beaver pond water level for 1999-2004 and its implications on the simulated NEE



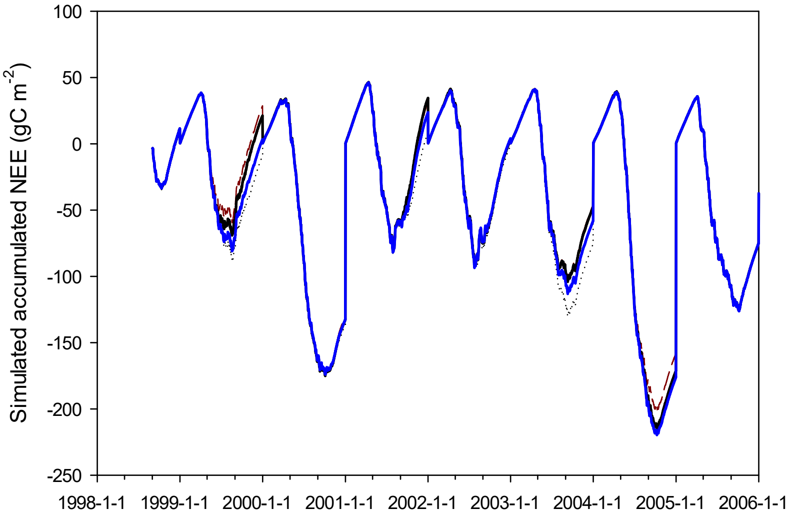


Figure S1: Beaver pond water level (refer to the average peat surface) with four assumptions and the simulated annual accumulated NEEs. Given the minor impacts on the results, the random series was used in the main paper.

B. Brief model descriptions of surface energy fluxes and their partitioning, evapotranspiration and aerodynamic resistance, plant water uptake, soil heat, photosynthesis, and respiration

To solve the peat hydrology, the model needs to estimate evapotranspiration, which is again closely linked to the surface energy partitioning and vegetation characteristics. CoupModel partitioned the energy fluxes according to the surface energy balance (eq.S1). Total net radiation, $R_{n,tot}$ was estimated by both net longwave radiation, i.e. LW_{out} - LW_{in} and short wave incoming radiation R_{is}. The latter R_{is} is one of the forcing variables.

$$\underbrace{\underbrace{\sigma(\varepsilon_s(T_s+273.15)^4}_{LW_{out}}-\underbrace{\varepsilon_a(T_a+273.15)^4)}_{LW_{in}}+(1-a_r)R_{is}}_{R_{n,tot}}=H+LE+q_h+\frac{dF}{dt} \qquad \text{(eq.S1)}$$

Where LW_{out} is the longwave radiation emitted from the ground calculated by using the simulated temperature of the soil surface (beneath the capitulum of the mosses), T_s with consideration of snow surface temperatures in winter. LW_{in} is the incoming longwave radiation from the atmosphere, calculated by using the measured air temperature, T_a. σ is the Stefan-Boltzman constant and the emissivity of the ground, ε_s was assumed to be 1. The emissivity of the atmosphere ε_a was estimated from Konzelmann et al. (1994) function. The surface albedo of ground, a_r is a simulated variable by considering the dynamic area cover of soil, snow, and canopy. Peat soil albedo was assumed to range from 5% (very wet) to 15% (very dry) depending on the soil surface water content (Kellner, 2001). Leaf albedo was set to a constant, 20%, and snow albedo was assumed to be a function of snow age, with 90% for newly formed snow but decreased to 40% after c.a. 1 month time (Gustafsson et al., 2004). Total net radiation is then partitioned into the sensible heat H, latent heat LE and the soil heat flux q_h, respectively. The last term dF/dt is the change in energy storage within the measured reference height and soil surface. Measured energy fluxes data at Mer Bleue show a high energy closure, i.e. 93% in Lafleur et al. (2001). Thus in our modelling study, dF/dt is assumed to be zero.

Beer's law was then applied to partitioning the net radiation between the two vegetation layers and soil surface.

$$R_{ns}=R_{n,tot}e^{-k_{rn}A_l} \qquad \text{(eq.S2)}$$

Where $R_{n,tot}$ is the net radiation above the plant canopy, R_{ns} is the net radiation at the soil surface (beneath the capitulum of the mosses), k_{rn} is an extinction coefficient, assume to be 0.5 and A_l is the leaf area index. The plant intercepted radiation, $R_{n,tot}$ - R_{ns} was then used for calculating the potential evapotranspiration and vegetation growth (see R_n in eq.S3). Given LAI of moss is ~1 in Mer Bleue bog, the light extinction for mosses is nearly complete within a few centimeters thus R_{ns} is very small (Frolking et al., 2002). We thus neglected the potential soil evaporation beneath the mosses induced by R_{ns}.

To calculate evapotranspiration E, CoupModel first calculated the potential evapotranspiration, E_{tp} by using Monteith (1965) equation,

$$E_{tp}=\frac{\Delta R_n+\rho_a c_p\dfrac{(e_s-e_a)}{r_a}}{\Delta+\lambda(1+\dfrac{r_s}{r_a})} \qquad \text{(eq.S3)}$$

Where R_n is net radiation available for evapotranspiration (i.e. $R_{n,tot}$ - R_{ns} in eq.S2), e_s is the vapour pressure at saturation, e_a is the actual vapour pressure, ρ_a is air density, c_p is the specific heat of air at constant pressure, Δ is the slope of saturated vapour pressure versus temperature curve, γ is the psychrometer "constant", r_s is an "effective" surface resistance and r_a is the aerodynamic resistance. The "effective" surface resistance r_s is the result of resistance to evapotranspiration exercised by plant stomata to regulate evaporation by vegetation.

The surface resistance in the leaf r_s in (eq.S3) was calculated using the Lohammar et al. (1980) function of leaf area index A_l, global radiation, R_{is}, and vapour pressure deficit, e_s - e_a,

$$r_s = \frac{1}{A_l \, g_l}$$

$$g_l = \frac{R_{is}}{R_{is} + g_{ris}} \frac{g_{\max}}{1 + \frac{(e_s - e_a)}{g_{vpd}}} \qquad \text{(eq.S4)}$$

Where g_l is stomata conductance, g_{ris} is global radiation intensity that represents half-light saturation in light response and g_{vpd} is vapor pressure deficit that corresponds to half reduction of stomatal conductance, g_{max} is the maximal conductance of fully open stomata for plants. Coefficients of moss surface resistance in the Lohammar equation (Table 1) were derived from previous analysis of evapotranspiration data measured by eddy covariance for bog systems (Kellner, 2001; Wu et al., 2010). In this study, the g_{max} of the shrubs was assumed to be 1.5 times the value of mosses (Table 1).

The aerodynamic resistance r_a in (eq.S3) is calculated by considering two components: One is the aerodynamic resistance as a function of wind speed and temperature gradients; the other is the aerodynamic resistance representing the influence of the vegetation cover. Under neutral conditions, r_a is calculated as,

$$r_a = \frac{\ln^2\left(\frac{z_{ref} - d}{z_o}\right)}{k^2 u} + r_{alai} A_l \qquad \text{(eq.S5)}$$

Where the measured wind speed, u, is given at the reference measured height, z_{ref}=3 m. k (=0.4) is von Karman's constant, d is the displacement height and z_o is the roughness length. To account for the plant height change with time, roughness length and displacement height were simulated variables, calculated based on the simulated height of each plant individually using the Shaw and Pereira (1982) function.

For the moss layer due to the presence of the above shrub layer, an additional contribution to the aerodynamics resistance, $r_{alai}A_l$ is added in (eq. S5) because of the eventual shadowing of the shrubs. The additional resistance was assumed proportional to the LAI of the shrub layer, with a scale parameter, r_{alai}, (Table 1). Under non-neutral conditions, the first term at the right-hand side of (eq. S5) is further corrected with the Monin-Obukhov stability function (Beljaars and Holtslag, 1991). This involves a dimensionless factor kB^{-1}. In our study, kB^{-1} = 2.3 was obtained from the synthesized value from available measured peatland data (Humphreys et al., 2006).

The actual evapotranspiration E is then calculated as the result of possible stresses at each soil layer depth, plant water uptake characteristics, and for shrubs, also influenced by root distributions (eq.S6). The influencing factors that reduce potential water uptake are drought, a lack of oxygen under water saturation conditions, and soil temperature.

$$E = E_{tp} \int_{z_r}^{0} f(\psi(z)) f(T(z)) r(z) \qquad \text{(eq.S6)}$$

Where for shrubs z_r is the depth with the deepest roots, set to 0.65 m below peat surface according to measured data from Moore et al. (2002). *r(z)* is the relative root density distribution, set to exponentially decrease with root depth z_r. $f(\psi(z))$, and $f(T(z))$ are response functions for soil water potential, and soil temperature at the modeled soil layer. $f(\psi(z))$ is the water potential response function that regulates the plant water uptake due to either too dry or too wet conditions.

We parameterize the $f(\psi(z))$ in the way that for the shrub layer when the water table is too close to the soil surface, ~ -0.1 m the roots water uptake would start to drop linearly to half of its optimum (i.e. response = 0.5). Moreover, the water uptake drops quickly when the simulated water table is below -0.6 m (Frolking et al., 2002). For the moss layer, no reduction of modeled water uptake occurs when the peatland water table is between ~ -0.4 to -0.1 m but decreases linearly either too dry or too wet. These settings were based on the empirical data from peatland vegetation (e.g. Schipperges and Rydin, 1998; Silvola and Aaltonen, 1984 and William and Flanagan, 1996).

$f(T(z))$ mimics the reduction of water uptake thus photosynthesis when the soil temperature is low, i.e. in winter. It is an exponential curve that ranges from 0 to 1 with increasing soil temperature. The mosses were assumed to reach optimum at ~ 3 ^{0}C but for the shrubs 15^{0}C (Mellander et al., 2006).

It needs to note the actual evapotranspiration also includes an additional uptake of water by shrub roots in soil layers with no water stress is calculated to compensate for other layers that are exposed to water stress, with a default degree of compensation.

Soil heat flux q_h in eq. (S1) is calculated by mainly considering heat conduction.

$$q_h = -k_h \frac{dT}{dz} \qquad \text{(eq.S7)}$$
$$k_h = h_1 + h_2\theta$$

Where k_h is the thermal conductivity of peat soil calculated by an empirical approach of De Vries (1975), dT/dz is the gradient of soil temperature with depth. k_h is assumed proportional to the soil water content, θ, and h_1 and h_2 are parameter values (Table 1).

The snow module of the model followed that of Gustafsson et al. (2001), except the snow melting coefficients for air temperature, M_T, and radiation, M_R (eq 4.33 in pp 194, of Jansson and Karlberg (2011)) is set to three folds of the default melting rate for forests.

Photosynthesis for each plant layer was modeled by a light-use approach (Monteith, 1965) and regulated by water and temperature.

$$C_{atm \to a} = \varepsilon_l \eta f(T_a) f(E/E_{tp}) R_s \qquad \text{(eq.S8)}$$

Where $C_{atm \to a}$ is the total plant growth, R_s is the global radiation absorbed by the canopy (see eq. 4), ε_L is the radiation use efficiency, $f(T_a)$, and $f(E/E_{tp})$ are response functions for temperature, and water. The light use efficiency for shrub and mosses were taken from the estimated value from Kross et al. (2016). The water response is calculated by using (eq.S6). The air temperature response function $f(T_a)$ for photosynthesis was different for the shrub and the moss layer. The shrub layer will start photosynthesis when the air temperature reaches above 5 ^{0}C, and increase linearly to 20 ^{0}C, from 20 to 25 ^{0}C the photosynthesis reaches the maximum, and above 25 ^{0}C photosynthesis decrease linearly and >= 35 ^{0}C the shrub stops its photosynthesis. A similar response function was used for the mosses except the mosses start photosynthesis at 0 ^{0}C, earlier than the shrubs, as been observed in Mer Bleue (Moore et al., 2006). Competition is enabled between the two plant layers for the interception of light with Beer's law and uptake of water.

Decomposition of soil organic matter is calculated by first-order kinetics as,

$$C_{DecompL} = k_l f(T) f(\theta) C_{litter} \qquad \text{(eq. S9)}$$

Where $C_{DecompL}$ is the decomposition rate of soil litter, by changing parameter k_l and pool size C_{litter}, the same equation is used to calculate the decomposition for the other soil organic matters, $f(\theta)$ is the response function for soil moisture, $f(T)$ is the response function for soil temperature, a Q10 temperature function was used. The first-order decay coefficients (Table 1) were set similarly to Frolking et al. (2010). A Q10 value of 3.0 was used (Table 1), according to the fitted value between the measured soil respiration flux and temperature data (Lafleur et al., 2005b). Plant respiration consists of growth respiration and maintenance respiration, where the growth respiration is controlled by recent photosynthesis while maintenance respiration is controlled by standing biomass, both further regulated by a Q10 temperature response function (Jansson and Karlberg, 2011).

C. Parameter values used in the reference model run reported in the main paper

Table S.1 Key model parameters used for Mer Bleue

Symbol	Parameters	Value	Unite	References
n	Coefficient in Van Genuchten function in acrotelm/ catotelm*	1.48/1.28	-	Weiss et al. (1998) Letts et al. (2000)
α	Coefficient in Van Genuchten function	0.123	-	
k_{sat}	Saturated hydraulic conductivity in acrotelm/ catotelm*	10^{-7} to 10^{-3} / 10^{-8} to 10^{-6}	m s^{-1}	Fraser et al., (2001)
a_{surf}	The first-order coefficient for surface runoff	0.8	-	Model default
d_p	Distance between peatland water logger to the beaver pond	250	m	Measured data at Mer Bleue
p_{cmax}	Surface max cover, shrub/moss	1/1	-	Roulet et al. (2007)
k_{rn}	Beer's extinction coefficient	0.5	-	Frolking et al. (2002)
p_{ck}	The sensitivity of reach max cover on LAI, shrub/moss	2/4	-	Moore et al. (2002)
z_r	The lowest shrub rooting depth	0.6	m	Lafleur et al. (2005)
ε	Light use efficiency, shrub/moss	0.7/0.25	g C MJ^{-1}	Kross et al., (2016)
θ_{Amin}	The minimum amount of air that is necessary to prevent a reduction of root water uptake, shrub/moss	35/0.1	vol %	Schipperges and Rydin, (1998); Silvola and Aaltonen, (1984) William and Flanagan, (1996)
ψ_c	Critical pressure head for reduction of potential water uptake, shrub/moss	60/40	cm water	
p_l	Coefficient determines how fast the reduction of potential water uptake when ψ_c is reached, shrub/moss	1/0.3	day^{-1}	
p_{mn}	Threshold Air temperature when photosynthesis starts, shrub/moss	5/0	^{0}C	Moore et al. 2006
$k_{l,shrub}$	First-order decomposition coefficient for shrub litter	0.32	$year^{-1}$	Frolking et al. (2010)
$k_{l,moss}$	First-order decomposition coefficient for moss litter	0.08	$year^{-1}$	
k_h	First-order decomposition coefficient for refractory organic matter	0.004	$year^{-1}$	
Q_{10}	Q10 value for decomposition	3	-	Lafleur et al., (2005)
$p_{\theta satact}$	Anaerobic activity	0.05	-	Metzger et al. (2015)
z_0	Surface roughness length	0.077	m	(Lafleur et al., 2005a))
kB^{-1}	Difference between the natural logarithm of surface roughness length for momentum and heat	2.3	-	Humphreys et al. (2006)

g_{ris}	Global radiation intensity that represents half-light saturation in light response	553.4	W m^{-2}	Kellner, (2001) Wu et al. (2010)
g_{vap}	Vapor pressure deficit that corresponds to half reduction of stomatal conductance	0.02	kpa	
g_{max}	Maximal conductance of fully open stomata for plants, shrub/moss	0.93/0.62	m s^{-1}	
r_{alai}	LAI Scale factor for r_a of the shrub layer	25	m s^{-1}	Metzger et al. (2015)
h_1	Thermal conductivity coefficient for peat soil	0.06	Wm^{-1}C^{-1}	De Vries (1975)
h_2	Thermal conductivity coefficient for peat soil	0.005	Wm^{-1}C^{-1}	

* Only mean values or ranges for acrotelm/ catotelm reported. Note overall eight soil layers are modeled for acrotelm and eight layers for catotelm thus coefficients for each layer might differ.

D. Additional measured variables used to validate the model output, including energy, hydrological fluxes, and vertical soil temperature profile

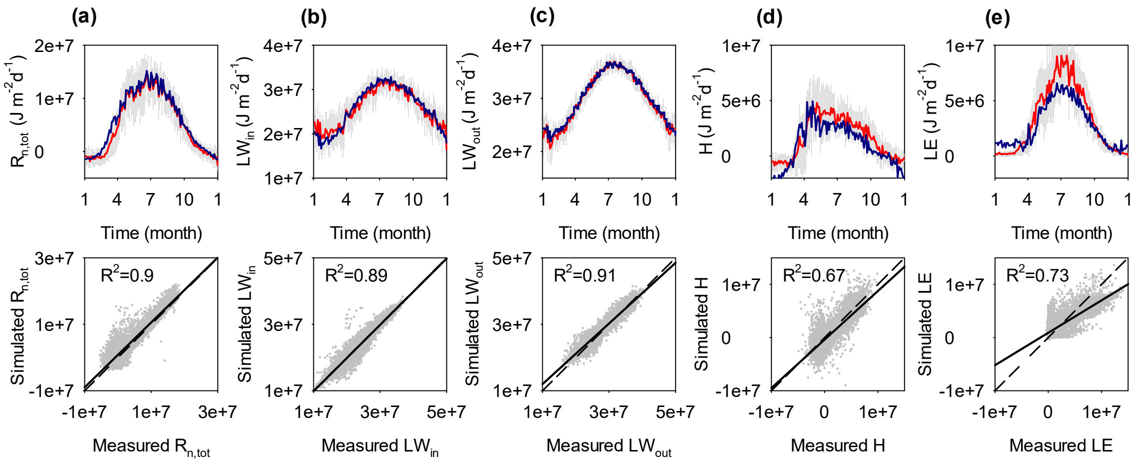


Figure S2: Mean annual seasonal cycle of simulated (blue line) and measured (red line ± standard deviation as grey) fluxes, and scatter plots of simulated vs. measured fluxes: (a) total net radiation $R_{n,tot}$, (b) incoming longwave radiation LW_{in}, (c) outgoing longwave radiation LW_{out}, (d) sensible heat H, and (e) latent heat flux LE. Linear least-squares regressions are fitted to the daily data (black line), 1:1 relationship shown as a faint dotted line, and R^2 denotes the coefficient of determination.

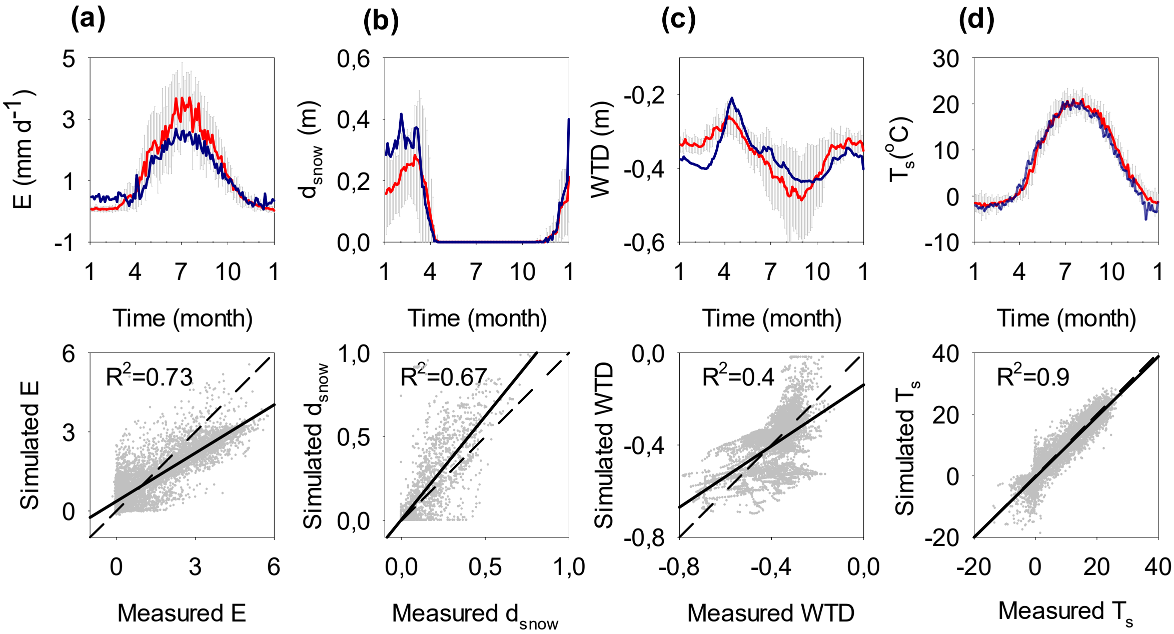


Figure S3: Mean annual seasonal cycle of simulated (blue line) and measured (red line ± standard deviation as grey) fluxes, and scatter plots of simulated vs. measured fluxes: (a) evapotranspiration E, (b) snow depth d_{snow}, (c) peatland water table depth WTD, and (d) soil surface temperature T_s. Linear least-squares regressions are fitted to the daily data (black line), 1:1 relationship shown as a faint dotted line, and R^2 denotes the coefficient of determination.

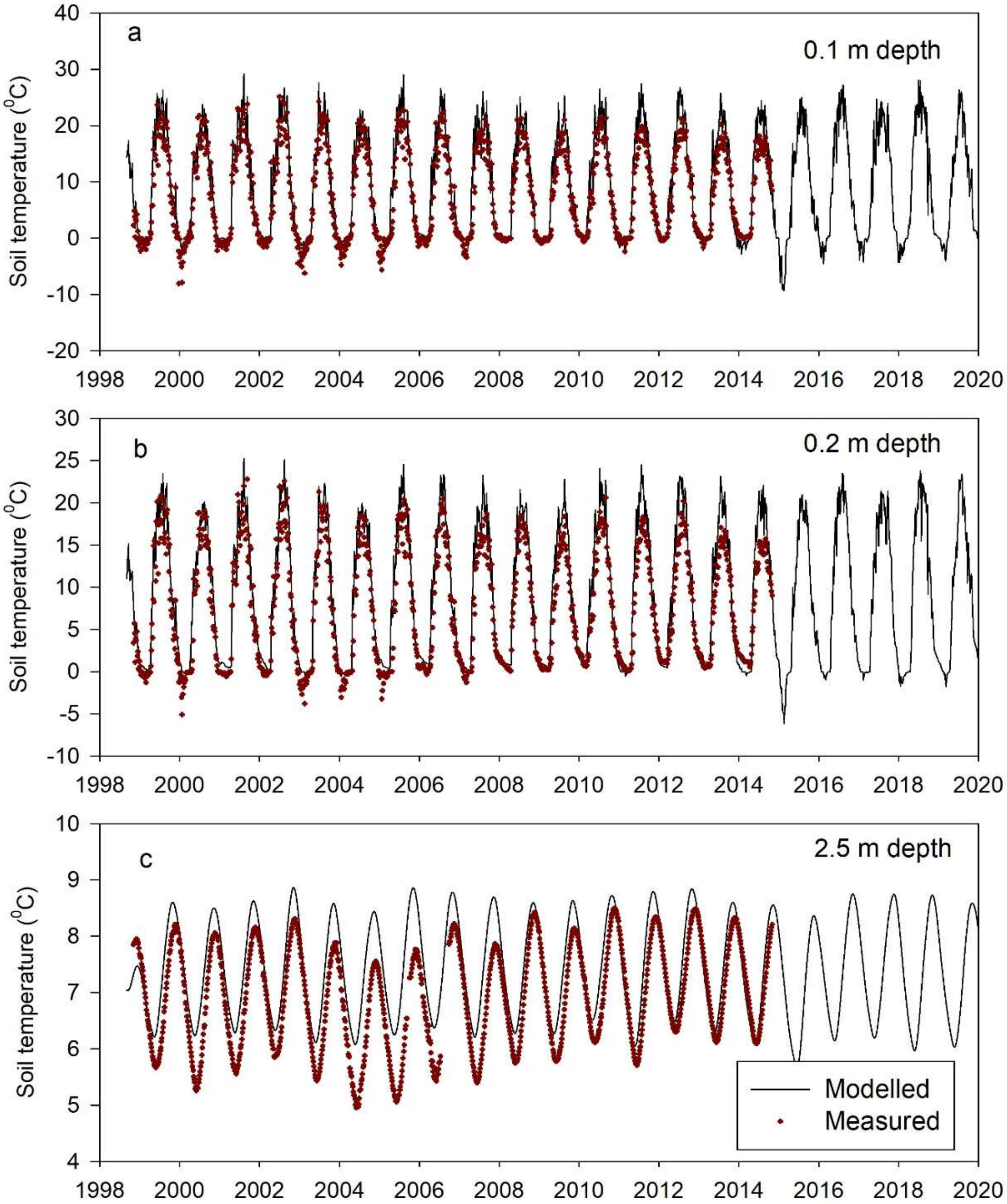


Figure S4 Simulated (line) and measured (dot) vertical soil temperatures at a) 0.1, b) 0.2, and c) 2.5 m depths. For clarity, 5-day averages are shown in the measured data time series.

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