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Supplement of

Modelling decadal trends and the impact of extreme events on carbon fluxes in a temperate deciduous forest using a terrestrial biosphere model

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Table S1. Monthly multipliers for the ERA-Land precipitation.

Month	Multiplier
1	1.37
2	1.45
3	1.47
4	1.61
5	1.50
6	1.87
7	1.69
8	1.84
9	1.80
10	1.60
11	1.33
12	1.79

S1 Scaling the ERA precipitation to site level values

The mean annual precipitation as estimated from the ERA-Land product was 465 mm, underestimating the site level observation (784 mm) by 68.8 %. We calculated the bias for different months and multiplied each value in the month by this multiplier, now shown in Table S1. These values were estimated by comparing the hourly data available from the site against the ERA-Land product in years 2014-2018.

Table S2. The leaf level values for the different tree species and their weighted average.

Tree species (coverage)	Leaf N (gm^{-2})	$J_{max,25}$ ($\mu mol\,m^{-2}\,s^{-1}$)	$V_{c(max),25}$ ($\mu mol\,m^{-2}\,s^{-1}$)	Chl_{Leaf} ($\mu g\,cm^{-2}$)
Red maple (60.4 %)	1.14 ± 0.15	113.54 ± 14.95	63.71 ± 8.99	38.87 ± 7.23
Large-tooth aspen (12.9 %)	1.85 ± 0.13	170.53 ± 30.00	86.01 ± 20.74	52.96 ± 12.21
Trembling aspen (12.4 %)	1.86 ± 0.30	141.20 ± 35.89	67.01 ± 17.39	53.52 ± 6.14
Ash (14.2 %)	1.12 ± 0.24	94.47 ± 19.74	56.62 ± 16.46	39.95 ± 10.58
Weighted average	1.32 ± 0.13	117.02 ± 24.22	63.54 ± 14.42	45.61 ± 7.87

S2 Calculation of weighted average

The weighted average of the tree trait variables was calculated by multiplying the value for each tree species (see Table S1) by its relative contribution and then summing all values, i.e. as

$$\bar{x} = \Sigma_{i=1}^{4} w_i x_i \tag{S1}$$

where $\bar{x}$ is the average, w_i is the percentage of the tree species coverage and the x_i is the tree species value.

S3 Implementation of age in the development of leaf chlorophyll

To slow down the development of the leaf chlorophyll in spring, we used leaf age factor, L_f, that was defined as a function of mean leaf age L_{age} (in days):

$$L_f = MIN(0.3 + 0.7 * L_{age}/d_{10}, 1.0) \tag{S2}$$

where d_{10} is a parameter defining for how long time the L_f will be less than one. By matching the development of the simulated leaf chlorophyll to the observed leaf chlorophyll, it was estimated to be 10 days. This L_f was then further used to adjust the fractions for the nitrogen usage as follows. The fraction for the structural part was adjusted to be

$$fN_{struc,cl} = k_0^{struc} + (1.0 - k_0^{struc})(1.0 - L_f) - k_1^{struc} L_f N_{leaf,cl} \tag{S3}$$

with the other parameter and variable names remaining as in Eq. 3. The fraction allocated to chlorophyll (fN_{chl}) was adjusted to:

$$fN_{chl} = \frac{k_0^{chl} - k_1^{chl} e^{-k_{fn}^{chl} LAI_{cl}}}{a_{chl}^n L_f} \tag{S4}$$

with the other parameter and variable names remaining as in Eq. 4.

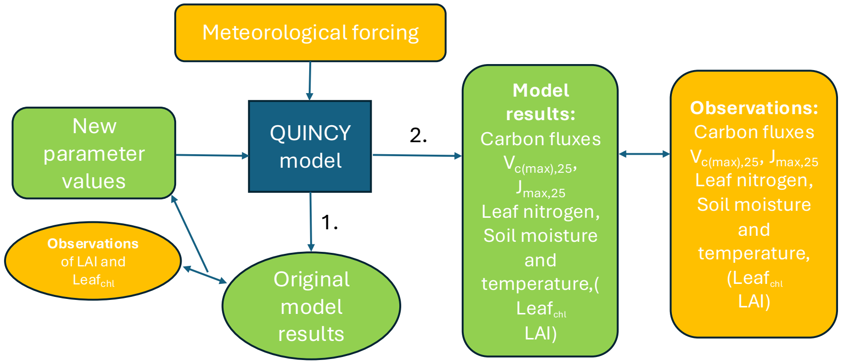

Figure S1. A schematic figure showing the workflow of the study. The model box is in dark blue, observation related variables in orange and model related variables in light green ovals. First (arrow denoted with 1) the original model results are compared to the observed LAI and Chl_{Leaf} and after that the model is run again with some new parameter values. After this (arrow denoted with 2) the model results are compared to different observations.

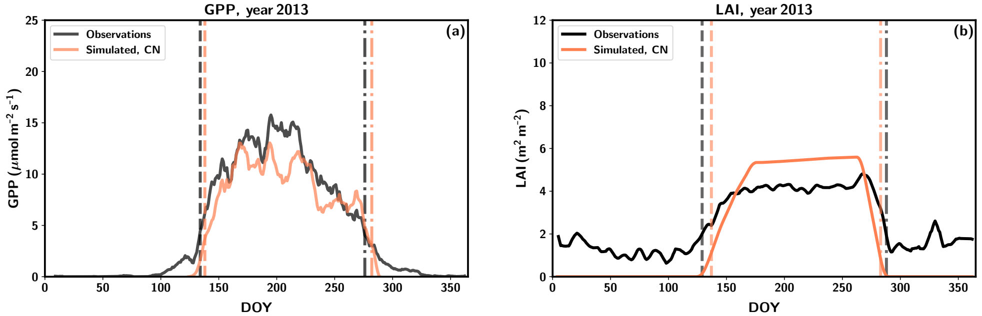

Figure S2. Seasonal cycle of GPP (a) and LAI (b) in 2013, smoothed with a seven-day averaging window. Black lines are observations and orange lines are QUINCY model results. The start of season (SOS) days are denoted by black (observations) and orange (simulations) vertical dashed lines. The end of season (EOS) days are denoted by black (observations) and orange (simulations) dash-dotted lines.

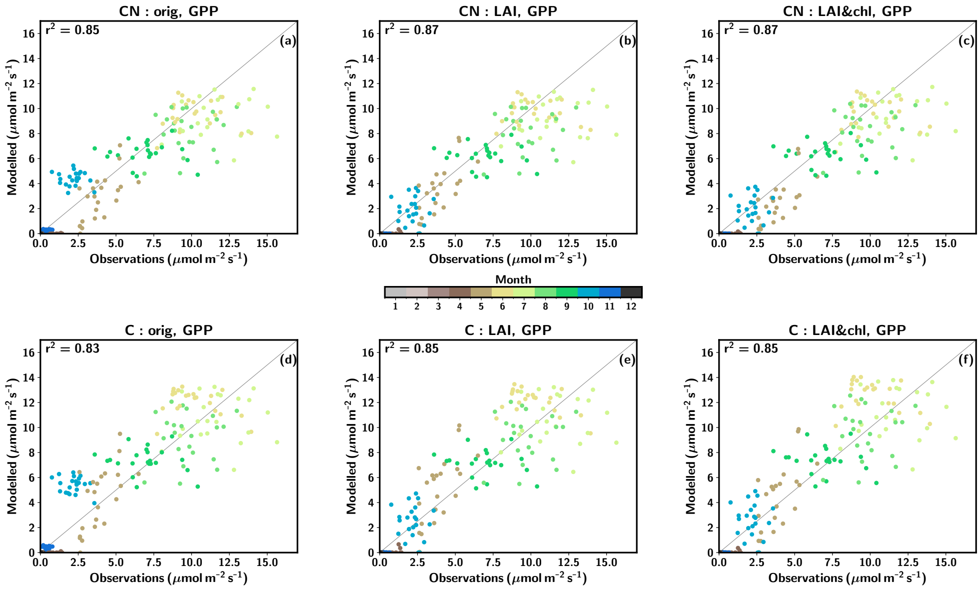

Figure S3. Scatter plot of observed monthly (in units $\mu\text{mol}\,\text{m}^{-2}\,\text{s}^{-1}$) GPP vs. simulated daily GPP from the C:orig (d), C:LAI (e), C:LAI&chl (f), CN:orig (a), CN:LAI (b), CN:LAI&chl (c). The values for different months are denoted by different colors.

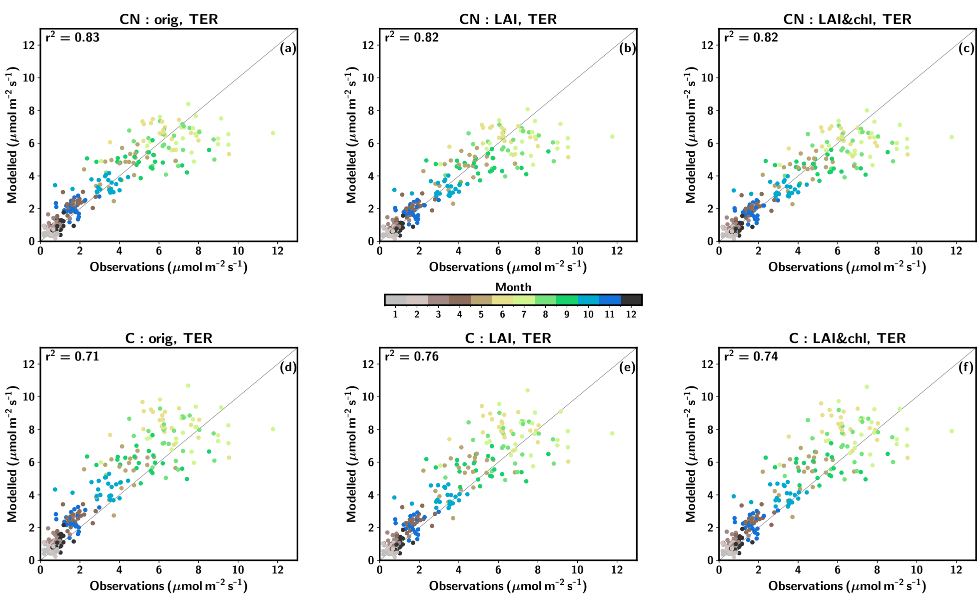

Figure S4. Scatter plot of observed monthly (in units $\mu\text{mol}\,\text{m}^{-2}\,\text{s}^{-1}$) TER vs. simulated daily TER from the C:orig (d), C:LAI (e), C:LAI&chl (f), CN:orig (a), CN:LAI (b), CN:LAI&chl (c). The values for different months are denoted by different colors.

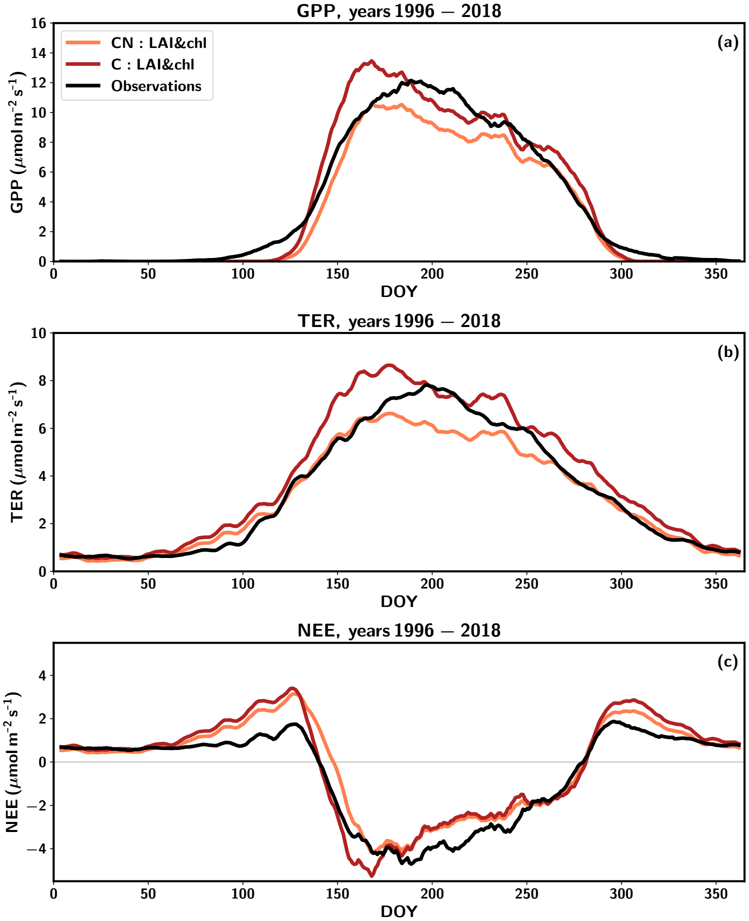

Figure S5. Averaged annual cycles of gross primary production, GPP (a), total ecosystem respiration, TER (b) and net ecosystem exchange, NEE (c) over 1996-2018. Observations are in black, the QUINCY results with C:LAI&chl in red and CN:LAI&chl simulations in orange. Both observations and model results have been smoothed with a seven-day averaging window.

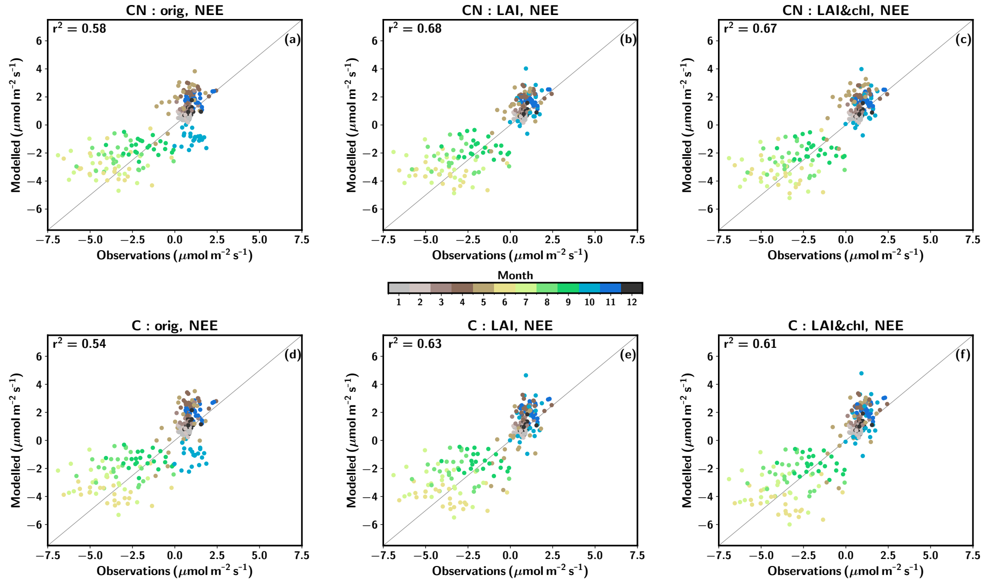

Figure S6. Scatter plot of observed daily (in units μmol m^{-2} s^{-1}) NEE vs. simulated daily NEE from the C:orig (d), C:LAI (e), C:LAI&chl (f), CN:orig (a), CN:LAI (b), CN:LAI&chl (c). The values for different months are denoted by different colors.

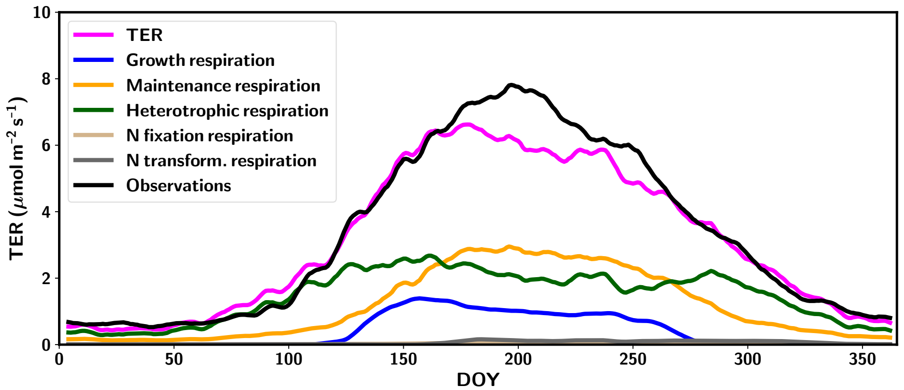

Figure S7. Seasonal cycle of the observed and simulated total ecosystem respiration (TER) from the CN:LAI&chl simulations, averaged over 1996-2018 and smoothed with a seven-day averaging window. The observation of TER in black, the simulated TER in magenta, the growth respiration in blue, the maintenance respiration in dark yellow and heteotrophic respiration in dark green. The N fixation respiration is in beige and N transformation respiration is in grey.

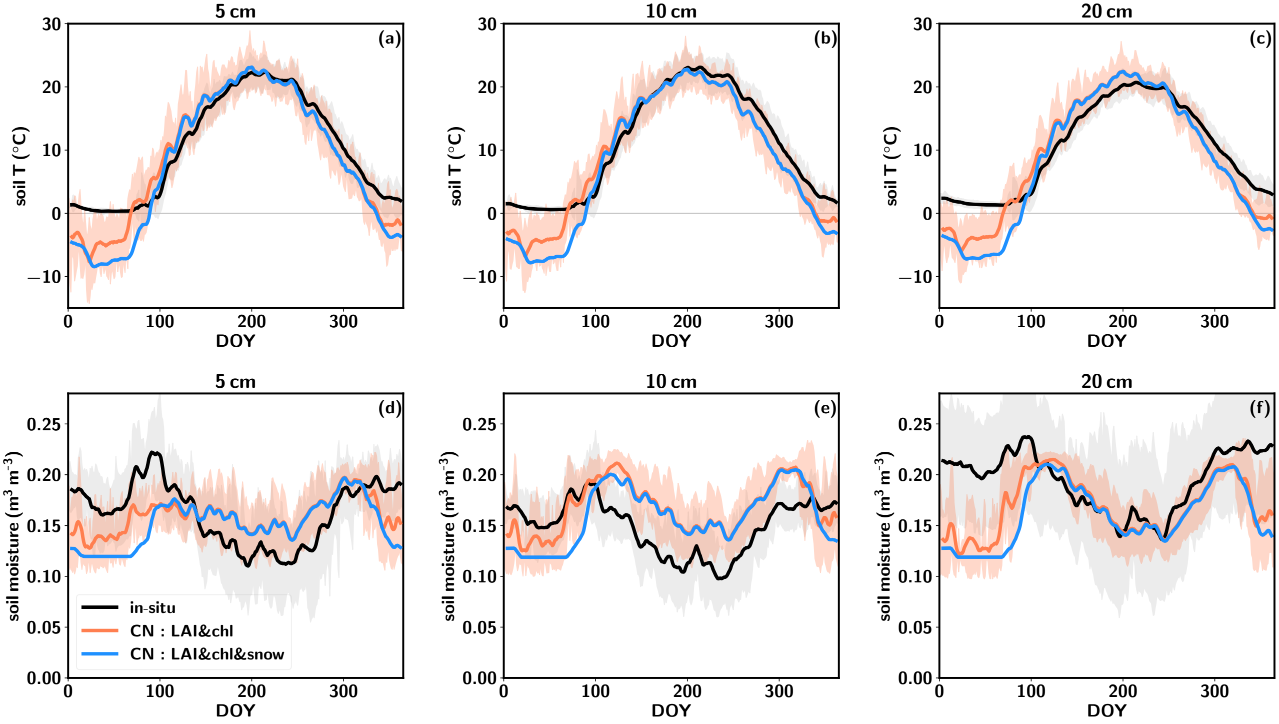

Figure S8. Seasonal cycles of soil temperature averaged over 2005-2015 at depths of 5 cm (a), 10 cm (b) and 20 cm (c) and of soil moisture at depths of 5 cm (d), 10 cm (e) and 20 cm (f). The observations are in black and CN:LAI&chl simulations in orange. The standard deviations are shown as shaded regions. The CN:LAI&chl&snow simulations are in blue. The results have been smoothed with a seven-day averaging window.

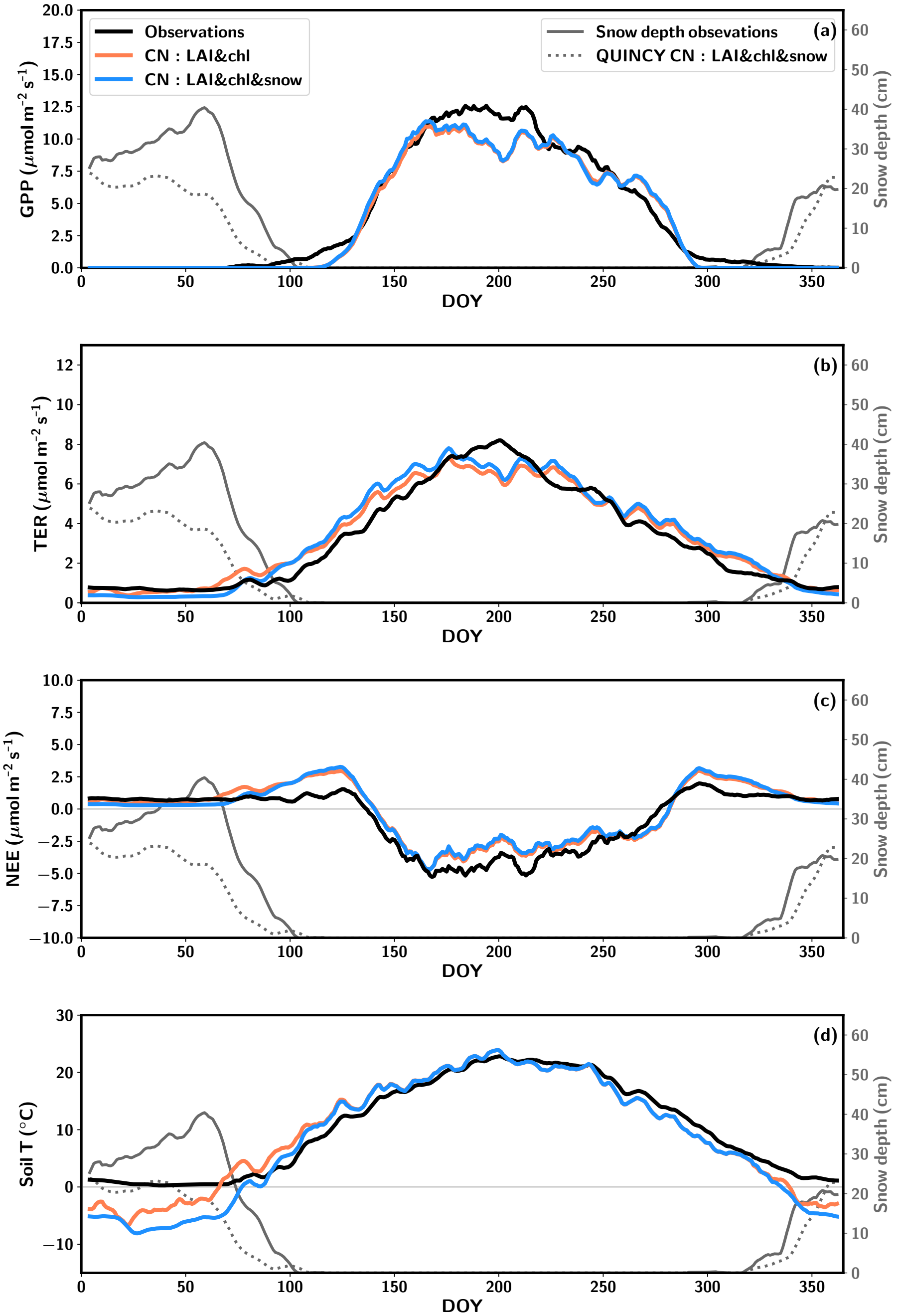

Figure S9. Averaged annual cycles of gross primary production, GPP (a), total ecosystem respiration, TER (b) and net ecosystem exchange, NEE (c), and soil temperature with snow depth over with 2008-2013. Observations of carbon fluxes and soil temperature are in black, the QUINCY results with C:LAI&chl in red and CN:LAI&chl simulations in orange. The observed snow depth is in solid gray line and simulated in dashed dray line. Both observations and model results have been smoothed with a seven-day averaging window.

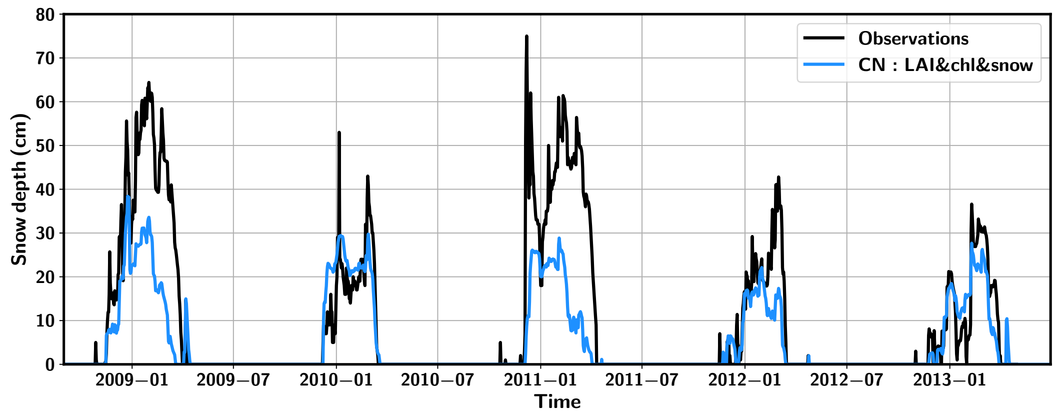

Figure S10. Daily snow depth over 2008-2013, observations are in black and simulation results in light blue.

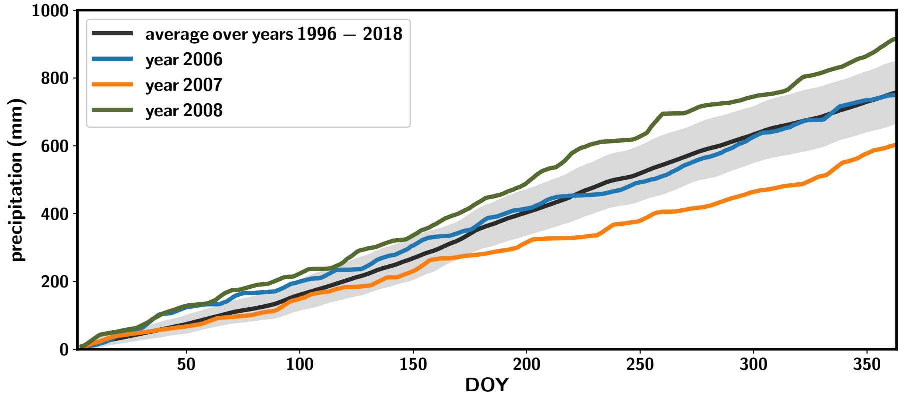

Figure S11. The cumulative rain fall, averaged for the years 1996-2018 (black line), year 2006 (blue line), year 2007 (orange line) and year 2008 (dark green line). Standard deviation for different years in shaded.

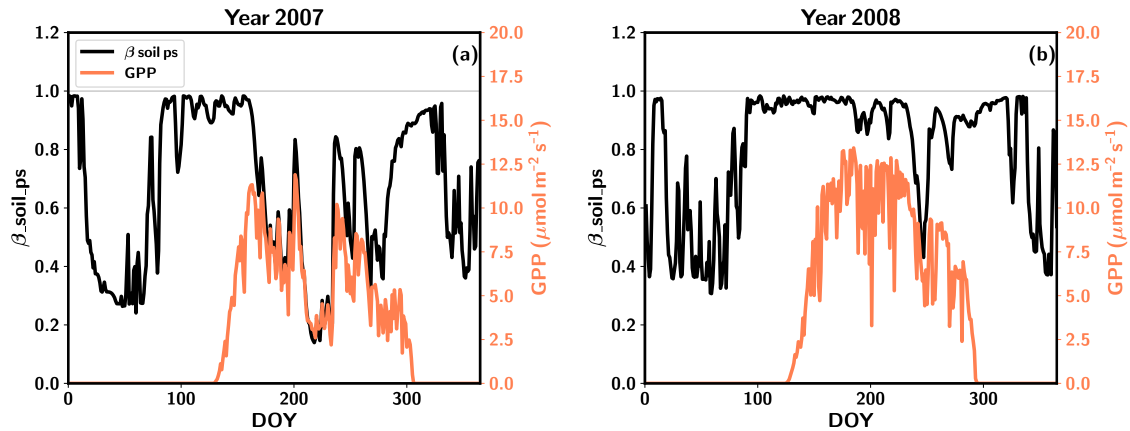

Figure S12. Simulated daily GPP in orange and β_{soil}, the factor that causes decline to the GPP levels due to soil moisture conditions, in black for years 2007 (a) and 2008 (b).

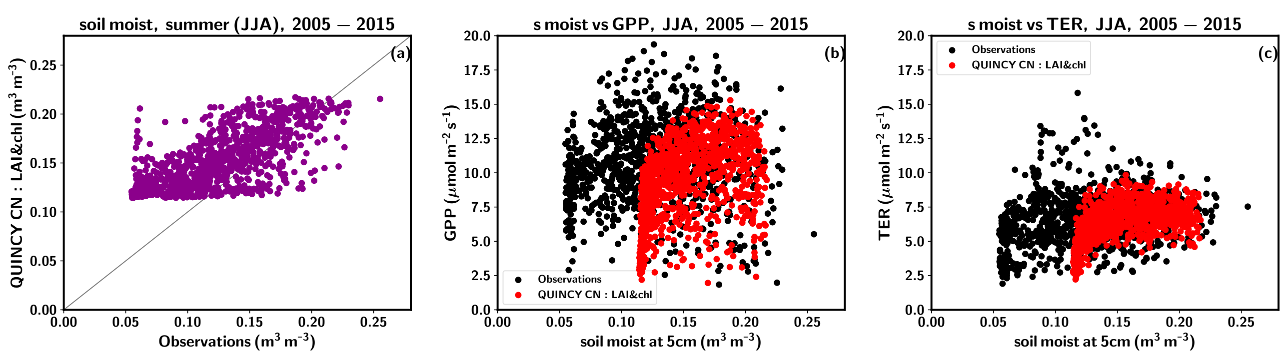

Figure S13. The observed vs. modelled soil observation values for summer months (June-July-August) (a) and simulated and observed GPP (b) and TER (c) values against simulated or observed soil moisture in 2005-2015. In (b) and (c) the observations are in black and simulated in red.

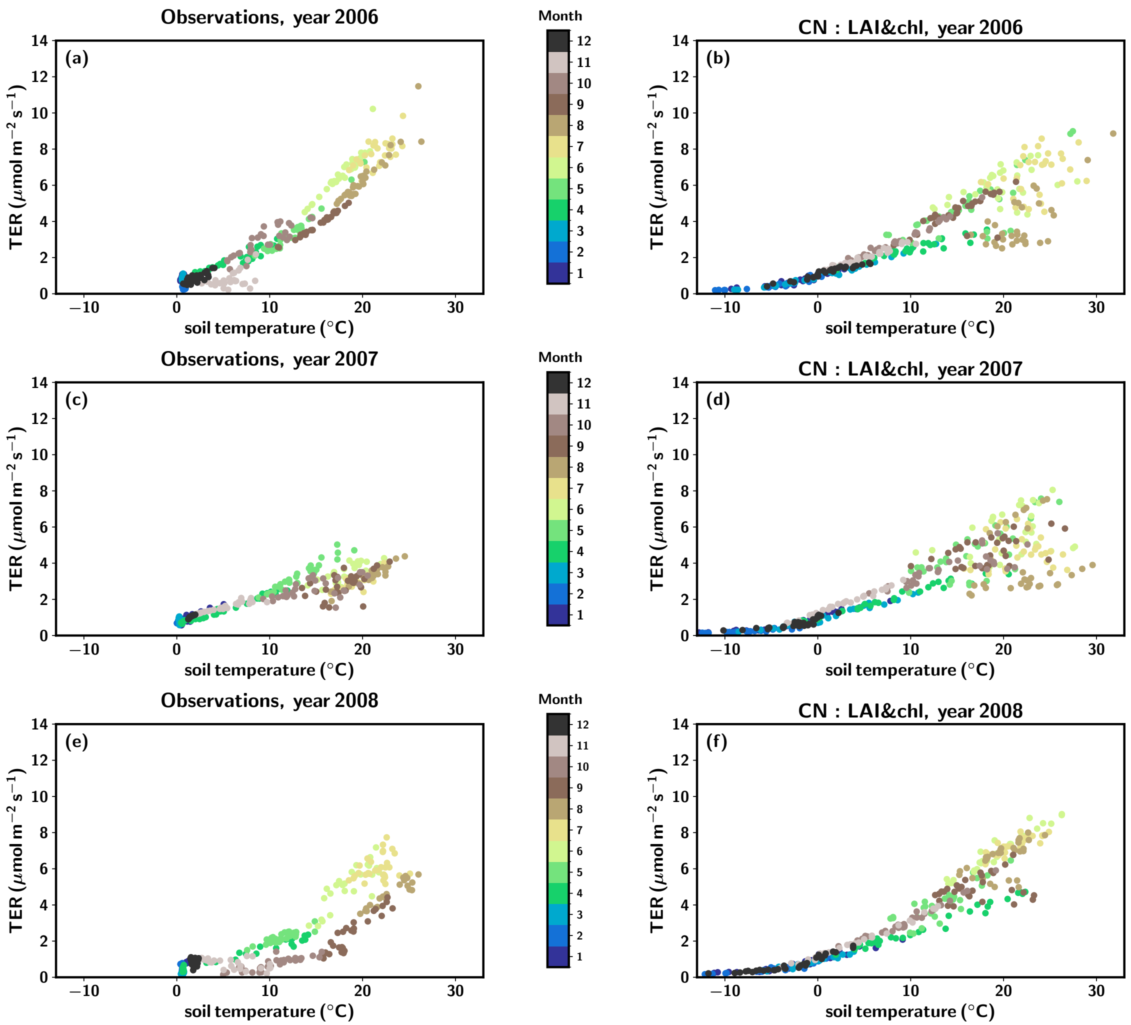

Figure S14. Total ecosystem respiration (TER) vs. soil temperature with color coding for different months. In (a, c, e) measurements for year 2006, 2007 and 2008, respectively. In (b, d, f) QUINCY results for 2006, 2007 and 2008, respectively.

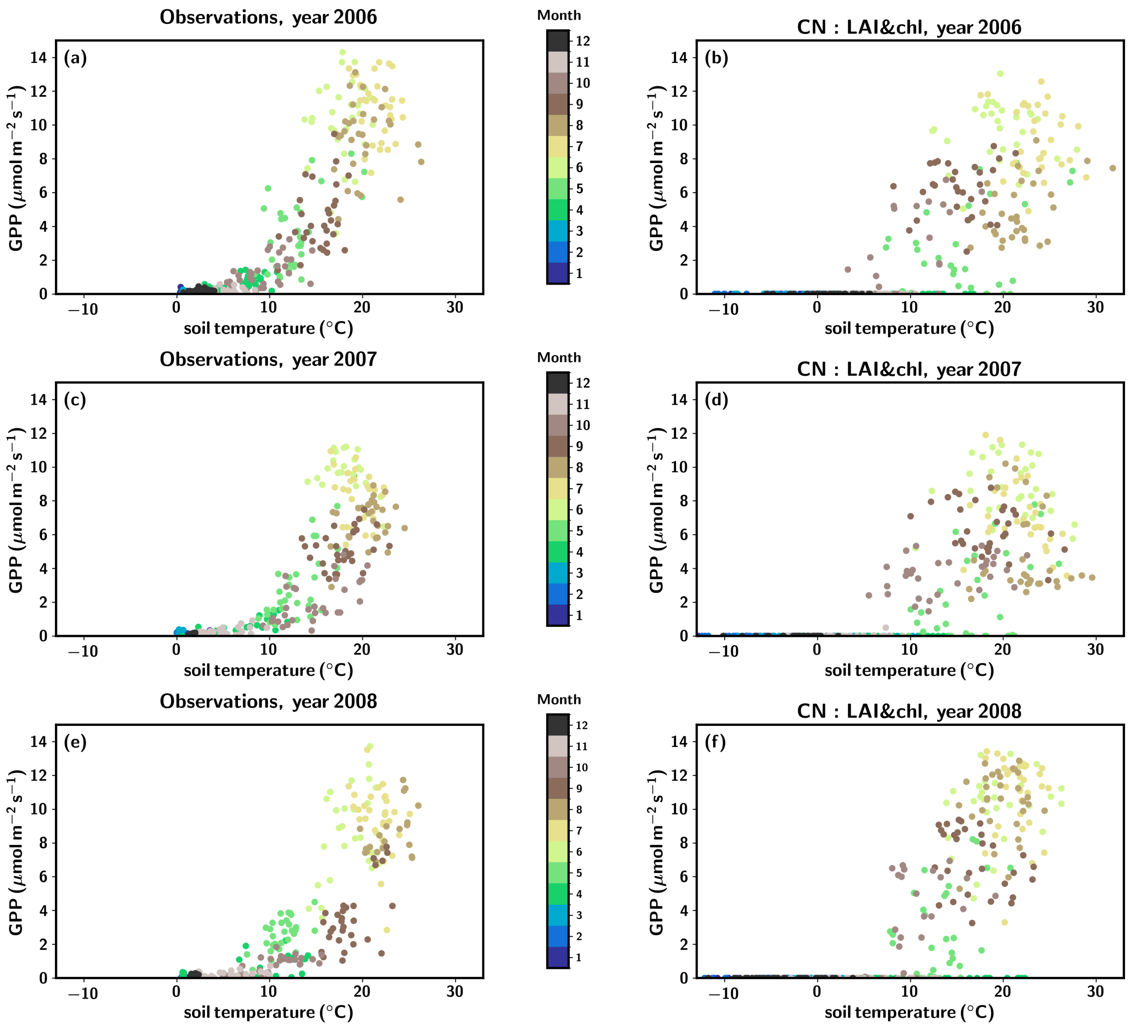

Figure S15. Gross primary production (GPP) vs. soil temperature with color coding for different months. In (a, c, e) measurements for year 2006, 2007 and 2008, respectively. In (b, d, f) QUINCY results for 2006, 2007 and 2008, respectively.

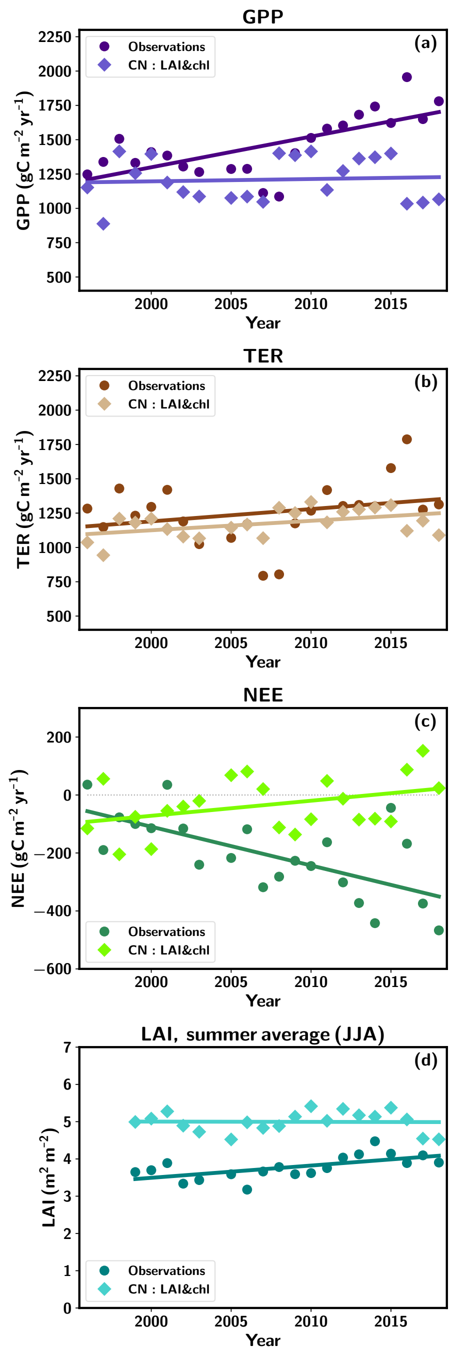

Figure S16. The annual values of GPP (a) (observations in violet circles, simulations in blue diamonds), TER (b) (observations in brown circles, simulations in light brown diamonds) and NEE (c) (observations in green circles, simulations in light green diamonds), and averaged summer time (June-July-August) values for LAI (d) (observations in petrol blue, simulations in cyan) with the fitted lines (the regression coefficients are given in Table S3.)

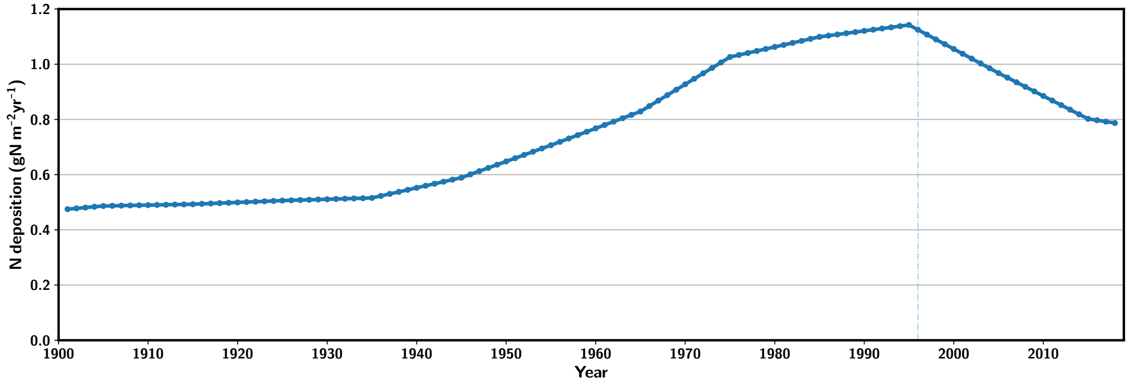

Figure S17. Annual nitrogen deposition that is used as input for the model simulation. Year 1996 is denoted with a dashed vertical line.

Table S3. The regression coefficients with their uncertainty range and Pearson R for the observed and simulated carbon fluxes (1996-2018). JFM stands for January, February and March, AM for April and May, JJA for June, July and August, SO for September and October, ND for November and December. The values for the significant trends (where $p < 0.05$) are written in bold and marked with an asterisk. An dash denotes a value that was not possible to determine.

Flux observations	GPP		TER		NEE	
season	regr. coef	Pearson R	regr. coef	Pearson R	regr. coef	Pearson R
JFM ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	-0.13 [-0.27 – 0.01]	-0.39	0.19 [-0.22 – 0.59]	0.20	0.32 [-0.07 – 0.70]	0.34
AM ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	0.26 [-1.11 – 1.64]	0.08	0.89 [-0.41 – 2.19]	0.29	0.63 [-0.55 – 1.80]	0.23
JJA ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	**5.76*** **[3.84 – 7.68]**	0.80	1.16 [-1.40 – 3.71]	0.20	**-4.61*** **[-6.04 – -3.17]**	-0.82
SO ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	**2.59*** **[0.65 – 4.54]**	0.51	1.19 [-0.84 – 3.22]	0.25	**-1.41*** **[-2.38 – -0.43]**	-0.54
ND ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	-0.13 [-0.39 – 0.14]	-0.21	0.40 [-0.22 – 1.01]	0.28	0.53 [-0.01 – 1.06]	0.40
yearly (gC m-2 yr-1 yr-1)	**22.35*** **[11.88 – 32.83]**	0.69	8.98 [-4.71 – 22.66]	0.28	**-13.38*** **[-20.15 – -6.61]**	-0.66

QUINCY CN:LAI&chl	GPP		TER		NEE	
season	regr. coef	Pearson R	regr. coef	Pearson R	regr. coef	Pearson R
JFM ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	0.00 [0.00 – 0.00]	-	0.20 [-0.16 – 0.56]	0.24	0.20 [-0.16 – 0.56]	0.24
AM ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	0.68 [-1.17 – 2.53]	0.16	**1.02*** **[0.07 – 1.96]**	0.43	0.34 [-0.82 – 1.49]	0.13
JJA ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	-0.24 [-2.73 – 2.26]	-0.04	0.56 [-0.70 – 1.81]	0.19	0.79 [-0.60 – 2.18]	0.25
SO ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	0.53 [-0.85 – 1.90]	0.17	**0.92*** **[0.22 – 1.63]**	0.51	0.40 [-0.92 – 1.71]	0.13
ND ($gC\,m^{-2}\,month^{-1}yr^{-1}$)	0.00 [0.00 – 0.00]	0	0.38 [-0.22 – 0.97]	0.27	0.38 [-0.22 – 0.97]	0.27
yearly (gC m-2 yr-1 yr-1)	1.70 [-8.79 – 12.20]	0.07	**6.90*** **[1.16 – 12.64]**	0.47	5.20 [-0.39 – 10.78]	0.38