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Supplementary Materials for

Water scaling of ecosystem carbon cycle feedback to climate warming

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Table S1. Site information in global meta-analysis. MAP-mean annual precipitation, MAT-mean annual temperature, ST-soil temperature.

Studies	Ecosystem	Latitude	Longitude	MAP	MAT	ST.change	Warming.method	Reference
s1	Wetland	46.85	-88.37	833	4.5	1.9	Infrared lamps	(*41*)
s2	Alpine grassland	34.82	92.93	290.9	-3.8	1.59~2.09	Infrared heater	(*42*)
s3	Alpine grassland	31.44	92.02	431.7	-1.2	1.52	OTCs	(*43*)
s4	Temperate grassland	44.50	123.52	471	6.4	1.7	Infrared radiators	(*44*)
s5	Wetland	61.78	24.30	700	3.5	0.3	OTCs	(*45*)
s6	Wetland	62.21	23.38	700	3.5	1.1	OTCs	(*45*)
s7	Wetland	67.98	24.20	700	3.5	0.5	OTCs	(*45*)
s8	Abandoned farmland	43.07	-81.33	595	7.5	0.7	Infrared heater	(*46*)
s9	Temperate grassland	42.03	116.28	382.3	2.1	1.2	Infrared heater	(*11*)
s10	Tundra	70.45	-157.40	139	-11.9	1.5	OTCs	(*47*)
s11	Tundra	71.30	-156.67	113	-12.6	1.5	OTCs	(*47*)
s12	Tundra	68.63	-149.57	250	-8.6	1.5	OTCs	(*47*)
s13	Tundra	78.88	-75.92	200	-14.6	1.5	OTCs	(*47*)
s14	Tallgrass prairie	34.98	-97.52	914	16.3	2.8	Infrared heater	(*48*)
s15	Tundra	70.37	-148.57	195	-11.6	1.13	OTCs	(*49*)
s16	Tundra	68.63	-149.57	250	-8.6	2.5~3	OTCs	(*50*)
s17	Temperate grassland	42.03	116.28	382.3	2.1	1.07	Infrared heater	(*51*)
s18	Alpine grassland	36.95	100.85	454	1.34	1.03	OTCs	(*52*)
s19	Temperate grassland	41.79	111.90	280	3.4	2	Infrared heater	(*53*)
s20	Tundra	68.63	-149.57	250	-8.6	1.2	greenhouse	(*54*)
s21	Tundra	78.90	-75.92	200	-14.6	0.4~1.8	OTCs	(*55*)
s22	Temperate grassland	42.03	116.28	383	2.1	1.79	Infrared heater	(*56*)
s23	Tallgrass prairie	34.98	-97.52	914	16.3	2.79	Infrared heater	(*57*)
s24	Alpine grassland	34.82	92.93	329	-3.8	1.77	Infrared heater	(*58*)
s25	Wetland	55.35	-112.52	462	0.9	0.6~0.7	OTCs	(*59*)
s26	Alpine grassland	32.45	102.37	752.4	1.1	0.52~1.46	OTCs	(*60*)
s27	Tundra	71.32	-156.60	113	-12.6	2	silicon heaters	(*61*)
s28	Alpine grassland	36.71	100.79	291	-4.6	0.6	OTCs	(*62*)
s29	Alpine grassland	32.80	102.97	753	1.1	1.78~2.91	Infrared heater	This study
s30	Temperate grassland	42.03	116.28	494.5	2.4	0.4	Infrared heater	(*24*)
s31	Alpine grassland	31.44	92.02	430	-1.16	1.1~1.4	OTCs	(*63*)
s32	Alpine grassland	31.39	90.03	300	0	1.5	OTCs	(*63*)
s33	Temperate grassland	41.78	111.89	248	3.4	0.59	Infrared heater	(*64*)
s34	Temperate grassland	34.82	114.28	627	14.3	0.21~0.83	Infrared heater	(*65*)

Table S2. Effects of mean annual precipitation (MAP), mean annual temperature (MAT), experimental warming magnitude, duration, and their interactions on relative changes in NEP across global herbaceous ecosystems with a linear mixed-effect model. MAP, MAT, magnitude and duration are considered as fixed effect, while studies as random effect.

	Sum Sq	Mean Sq	NumDF	DenDF	F.value	Pr(>F)
MAP	11454.73	11454.73	1	36.31	5.22	0.03
MAT	518.72	518.72	1	25.64	0.24	0.63
duration	7993.24	7993.24	1	31.11	3.64	0.07
magnitude	1400.14	1400.14	1	40.94	0.64	0.43
MAP × MAT	433.26	433.26	1	25.56	0.20	0.66
MAP × duration	7224.87	7224.87	1	31.18	3.29	0.08
MAP × magnitude	1459.39	1459.39	1	40.99	0.66	0.42

Table S3. Repeated-measures ANOVA results (*F* values) on the effects of warming (*W*), year (*Y*), and their interactions on GEP, ER, NEP, ST (T_{soil}), and moisture (M_{soil}).

	GEP	ER	NEP	T_{soil}	M_{soil}
W	2.38***	5.02*	1.55	369.66***	237.65***
year	1024.08***	1442.01***	96.59***	1934.59***	1087.87***
W ×year	18.56***	10.88***	17.45***	9.02***	27.02***

Level of significance: ***: $P < 0.001$; **: $0.001 \leq P < 0.01$; *: $0.01 \leq P < 0.05$

Table S4. Repeated-measures ANOVA results (*F* values) on the effects of warming (*W*), measured time (*T*), and their interactions on GEP, ER, NEP, ST (T_{soil}), and moisture (M_{soil}) in 2014–2016.

	GEP	ER	NEP	T_{soil}	M_{soil}
2014					
W	2.15	13.63**	0.55	37.47***	71.85***
T	273.51***	260.71***	105.75***	395.60***	444.74***
W × T	6.36***	3.16**	7.32***	7.72***	8.97***
2015					
W	12.90**	4.66*	21.22***	267.13***	56.28***
T	100.58***	114.24***	51.06***	220.59***	290.76***
W × T	9.29***	8.96***	6.59***	17.80***	19.88***
2016					
W	69.07***	5.99*	15.42***	348.95***	217.98***
T	779.30***	254.96***	63.71***	282.83***	478.84***
W × T	48.94***	14.17***	5.20***	2.27*	11.61***

Level of significance: ***: $P < 0.001$; **: $0.001 \leq P < 0.01$; *: $0.01 \leq P < 0.05$

Table S5. Comparison of the nonthreshold and threshold models based on the AIC for GEP, ER, and NEP.

Model	GEP	ER	NEP
(1)	413.42	311.93	309.19
(2)	378.01	321.17	279.27
(3)	388.96	311.75	310.49
(4)	347.70	280.30	266.94

Nonlinear model was chosen due to its lower AIC.

Table S6. Coefficients of threshold model (means and 95% confidence intervals) (Eq. 4). Abbreviations of the carbon fluxes: gross ecosystem productivity (GEP), ecosystem respiration (ER), net ecosystem productivity (NEP).

	γ_1		γ_2		γ_3	
GEP	0.4843	(0.3542, 0.6572)	-0.0084	(-0.0117, -0.0060)	0.0624	(0.0430, 0.0819)
ER	0.1973	(0.1424, 0.2706)	-0.0032	(-0.0045, -0.0022)	0.0766	(0.0569, 0.0965)
NEP	0.3182	(0.2220, 0.4525)	-0.0060	(-0.0087, -0.0041)	0.0454	(0.0224, 0.0683)

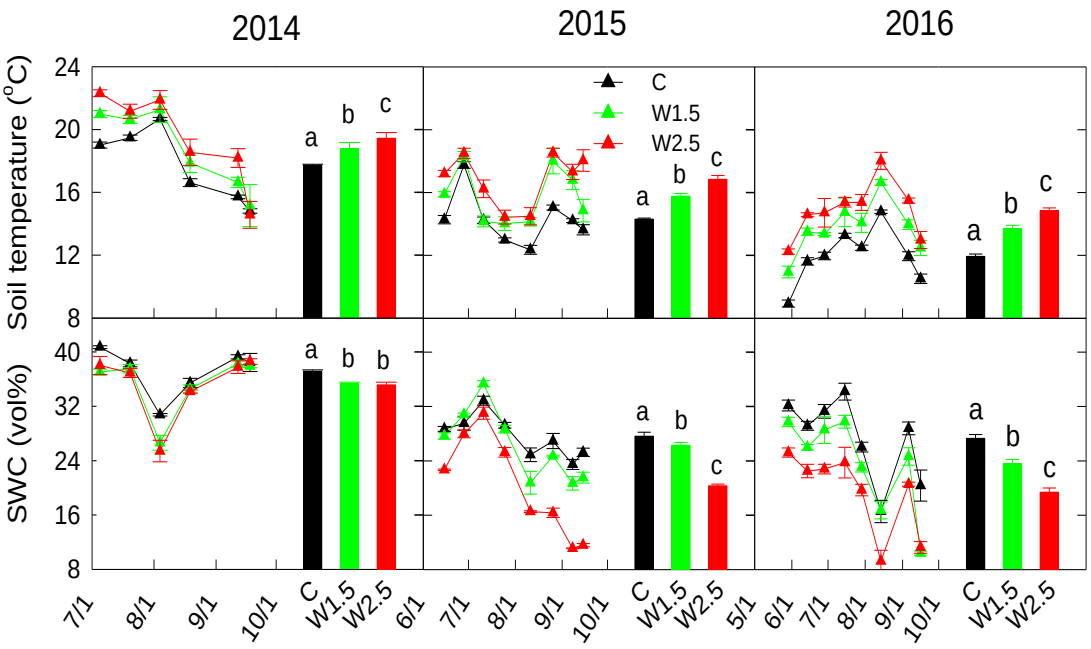

Fig. S1. Seasonal dynamics and means of ST and SWC at 10-cm depth under three warming treatments in 2014 to 2016. C: control; W1.5: low-level warming; W2.5: high-level warming. Different letters above the bars indicate a significant difference between treatments.

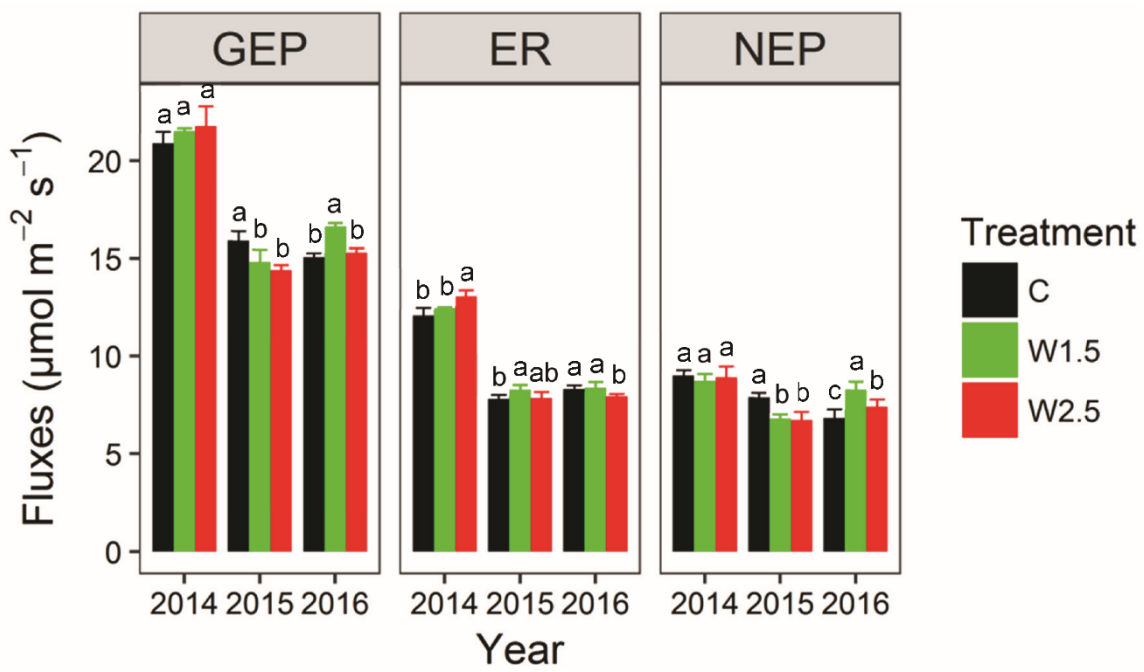

Fig. S2. Seasonal means of GEP, ER, and NEP under different warming treatments in 2014 to 2016. C: control; W1.5: low-level warming; W2.5: high-level warming. Different letters above the bars indicate a significant difference between treatments in each year.

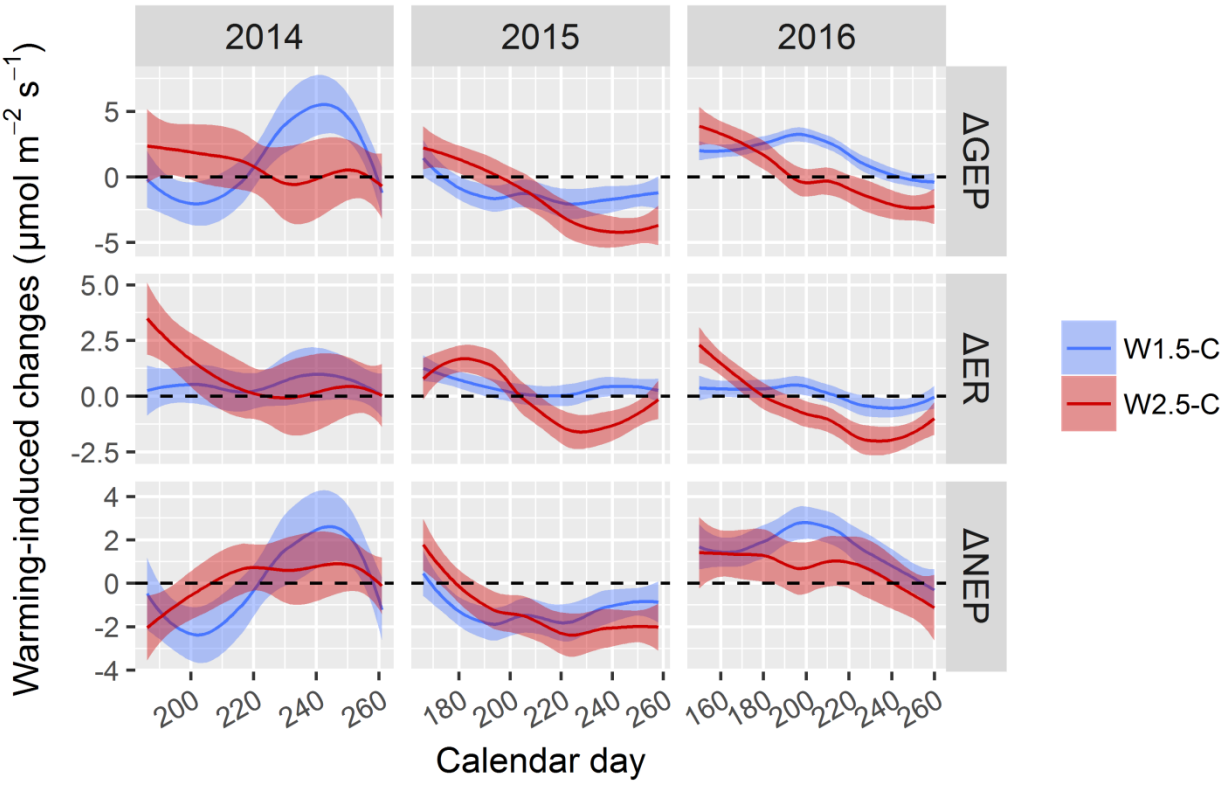

Fig. S3. Warming-induced changes in GEP, ER, and NEP within the year. C: control; W1.5: low level warming; W2.5: high level warming; W1.5-C represents the warming effect calculated as the W1.5 treatment minus the Control, and W2.5-C means the warming effect as the W2.5 treatment minus the Control.

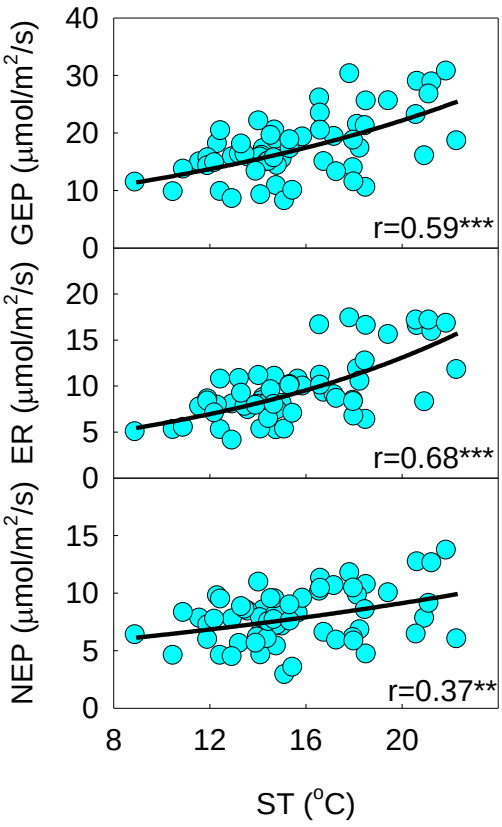

Fig. S4. Relationships between ST and GEP, ER, or NEP across seasons and plots.
Level of significance: ***: $P < 0.01$; **: $0.01 \leq P < 0.05$.

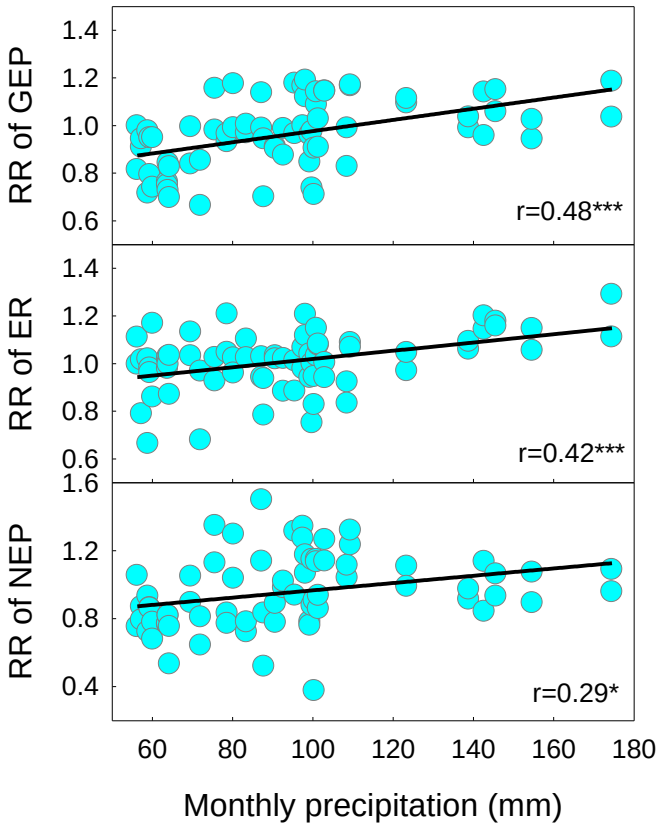

Fig. S5. Relationships between warming-induced response ratio of ecosystem carbon fluxes with monthly precipitation. The RR was quantified by treatment/control. GEP-gross ecosystem productivity, ER-ecosystem respiration and NEP-net ecosystem productivity. Level of significance: ***: $P < 0.01$; **: $0.01 \leq P < 0.05$; *: $0.05 \leq P < 0.1$.

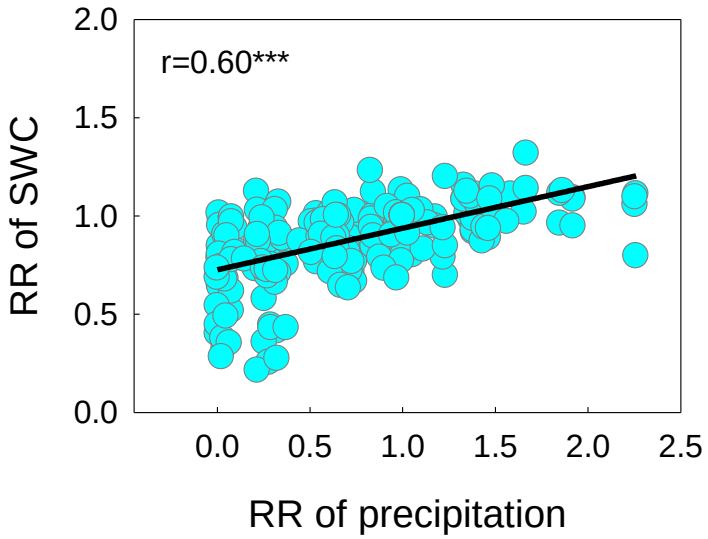

Fig. S6. The relationship between response ratio of monthly mean SWC and monthly precipitation in a precipitation gradient experiment at our study site from 2015 to 2016. The experiment includes 6 precipitation treatments of 1/12p, 1/4p, 1/2p, 3/4p, p and 5/4p with p representing ambient precipitation in the growing season (See the detailed information in Zhang et al. 2018). The relative changes of precipitation and SWC were quantified by the response ratio (RR, treatment/control). Level of significance: ***: $P < 0.01$; **: $0.01 \leq P < 0.05$; *: $0.05 \leq P < 0.1$.

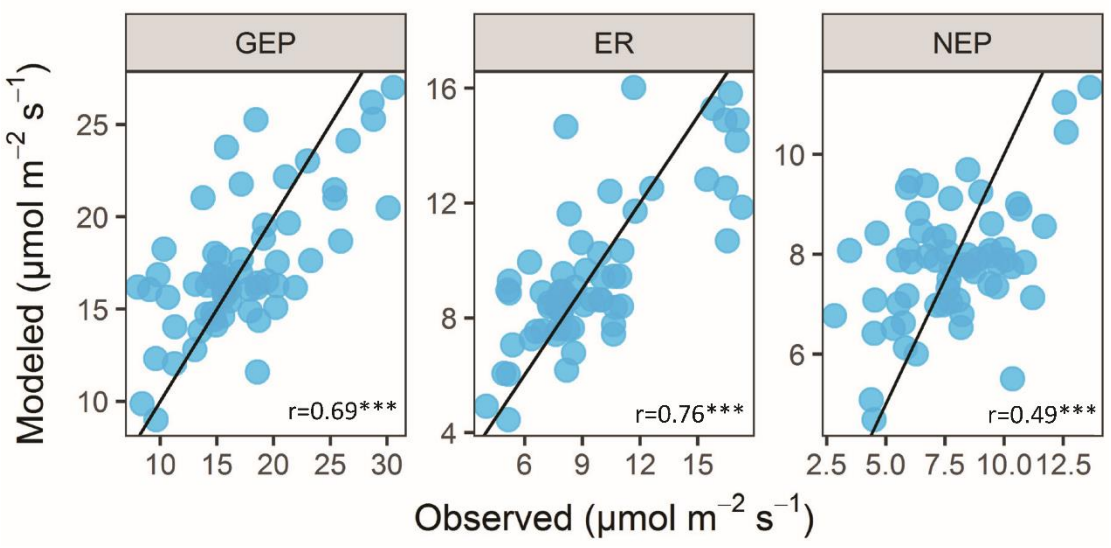

Fig. S7. Relationships between the modeled and observed values of carbon fluxes with 1:1 line. Level of significance: ***: $P < 0.01$; **: $0.01 \leq P < 0.05$; *: $0.05 \leq P < 0.1$. Abbreviations of the carbon fluxes: gross ecosystem productivity (GEP), ecosystem respiration (ER), net ecosystem productivity (NEP).

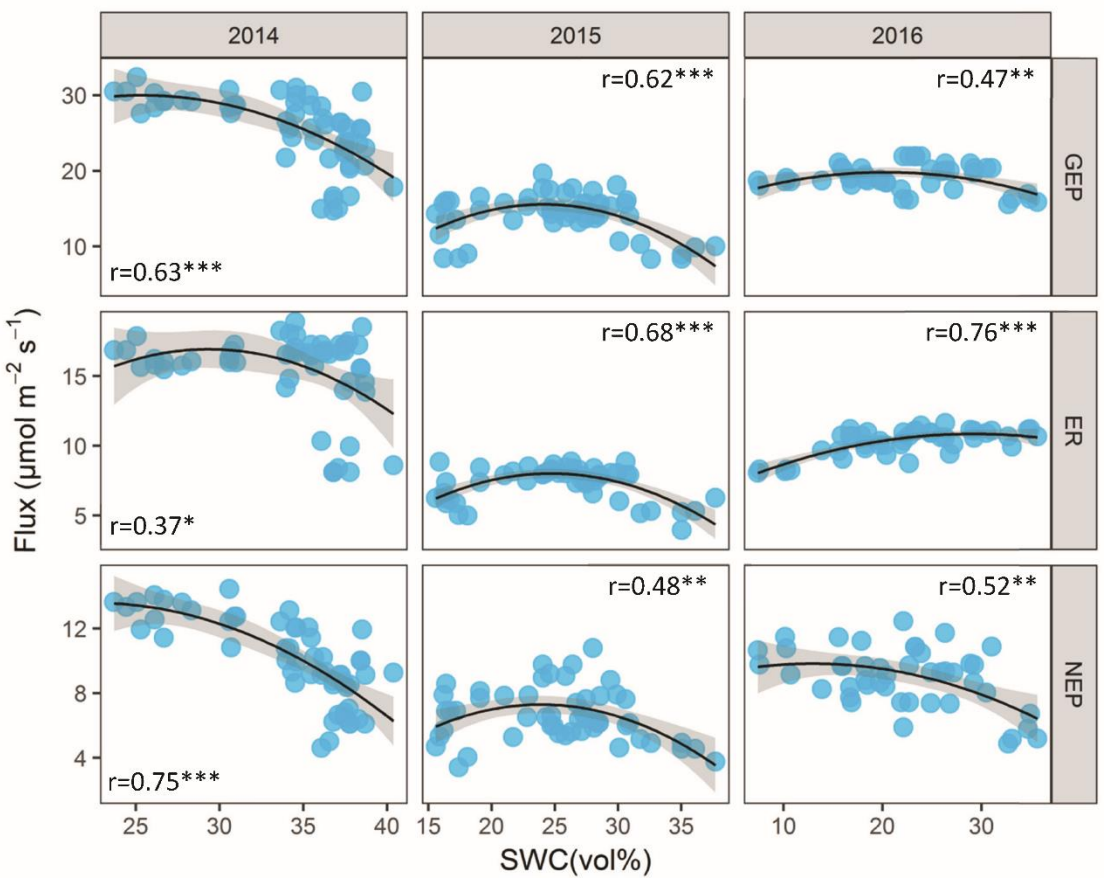

Fig. S8. Relationships between SWC and ecosystem C fluxes within peak growing seasons (July and August). Level of significance: ***: $P < 0.01$; **: $0.01 \leq P < 0.05$; *: $0.05 \leq P < 0.1$. Abbreviations of the carbon fluxes: gross ecosystem productivity (GEP), ecosystem respiration (ER), net ecosystem productivity (NEP).