Supplementary Information

Contrasting responses of water use efficiency to drought across global terrestrial ecosystems

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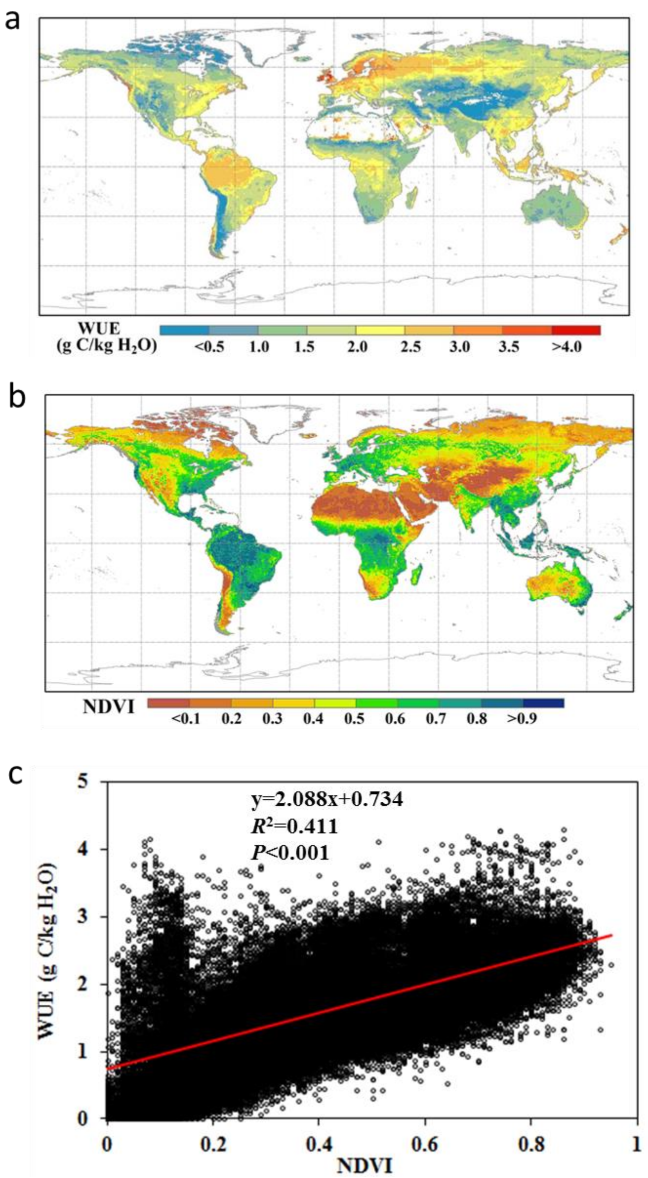
This supplementary material file includes:

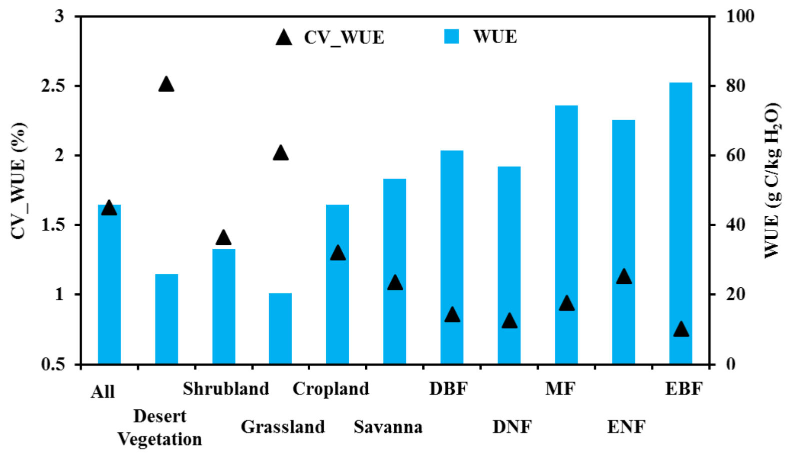
Supplementary Figures S1 to S8

Supplementary Tables S1

Section 1. Global spatial patterns of annual WUE and NDVI.

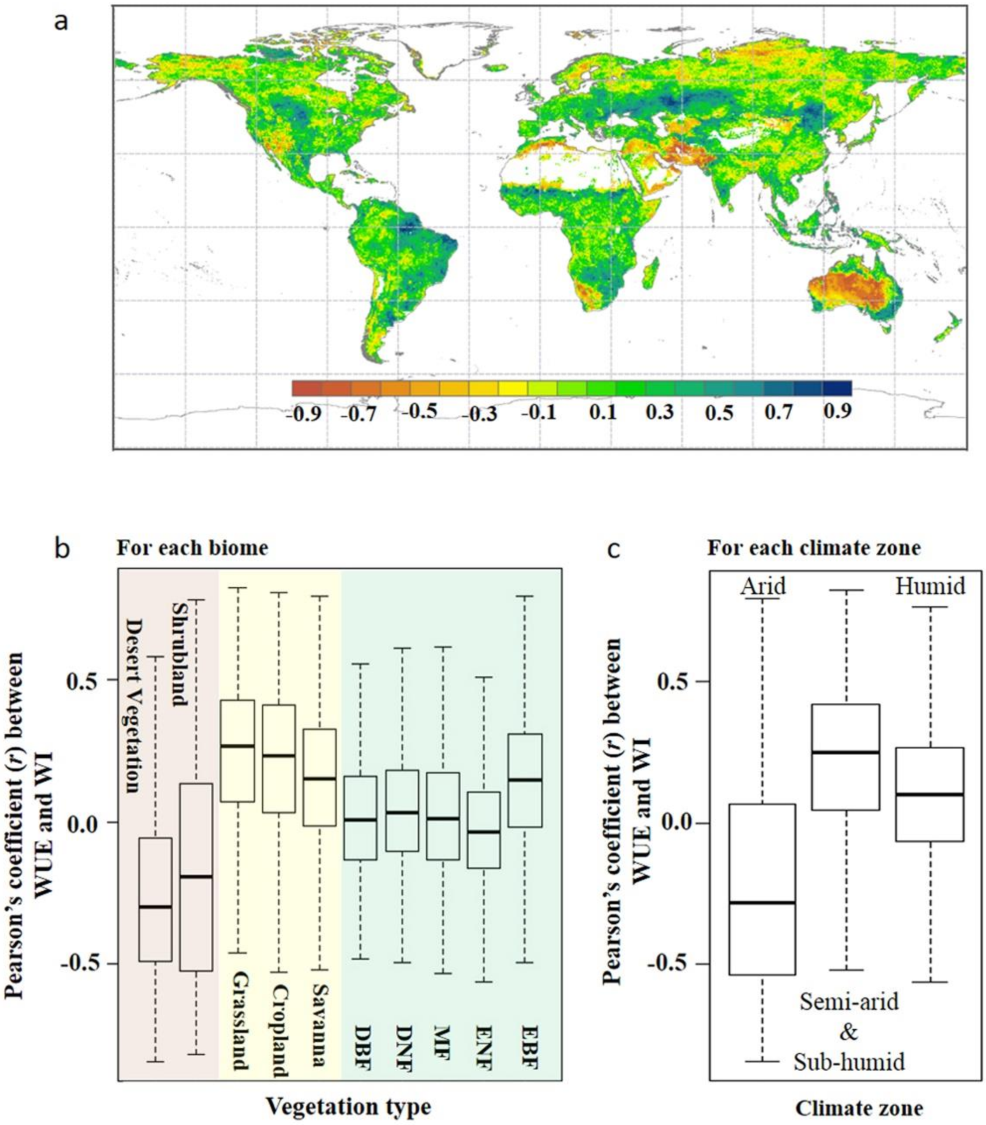


Supplementary Figure S1 Global distribution of mean annual WUE and NDVI over 1982-2011. (a) global distribution of mean annual WUE calculated over 1982-2011 based on the MTE data, (b) global distribution of mean annual NDVI over 1982-2011 calculated based on the AVHRR-GIMMS-3g NDVI dataset, and (c) relationship between mean annual WUE and NDVI over 1982-2011. The red solid line in (c) indicates the best linear fit. Note there are no MTE data over Sahara, Greenland and Antarctica regions. Map was drawn using ArcMap 10.2.

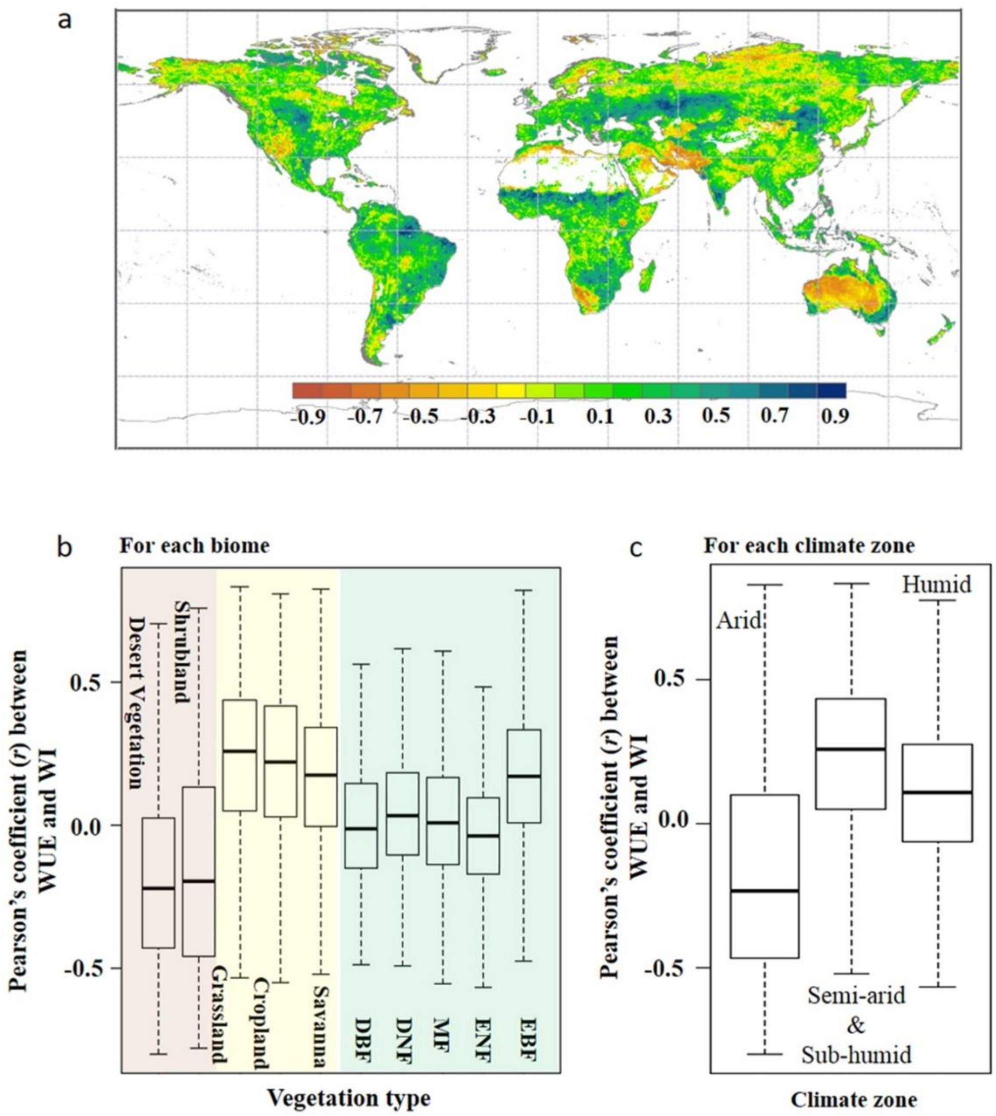


Supplementary Figure S2 Mean (1982-2011) and spatial variability of mean annual WUE for each vegetation type based on the MTE data. The spatial variability of the entire biome class is indicated by the coefficient of variation (CV). The results show that higher WUEs are generally found in forest ecosystems, whereas the spatial variability of WUE is lower in high WUE regions than in low WUE regions. Image was drawn using Excel 2013.

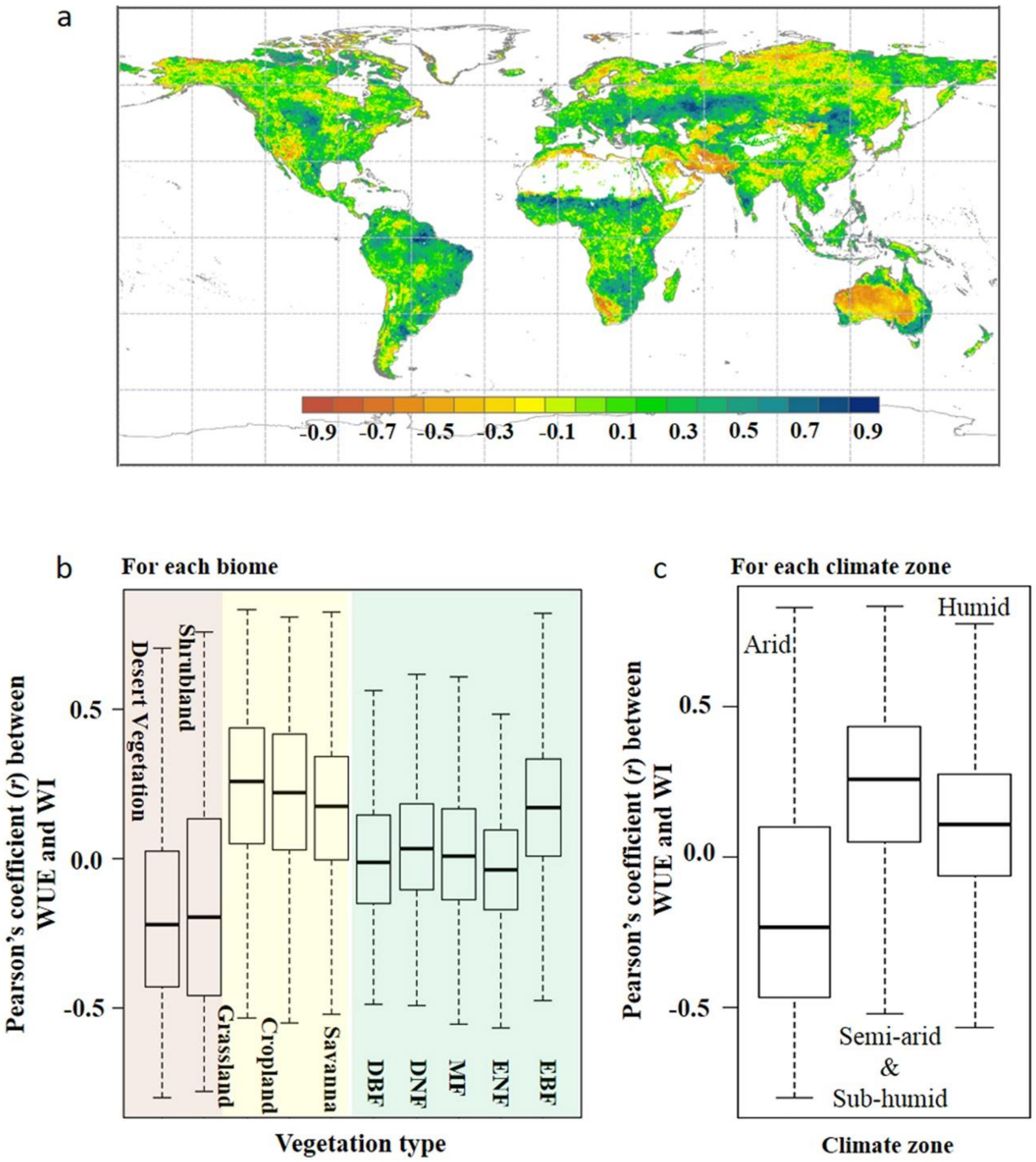
Section 2. Drought effect on the WUE



Supplementary Figure S3 Relationship between non-detrended annual MTE-WUE and PDSI series over 1982-2011. (a) Spatial distribution of Pearson's coefficient (*r*) between non-detrended annual MTE-WUE and PDSI series, (b) boxplot of Pearson's coefficient between non-detrended annual MTE-WUE and PDSI for each biome, (c) boxplot of Pearson's coefficient between non-detrended annual MTE-WUE and PDSI for each climate zone. The background colours in (b) indicate different climate zones (red: arid zone; yellow: semi-arid/sub-humid zone; green: humid zone). The interpretation of the boxplots is given in Figure 2. Map was drawn using ArcMap 10.2 and boxplots were drawn using R 3.1.2.



Supplementary Figure S4 Relationship between detrended annual MTE-WUE and WI series over 1982-2011. (a) Spatial distribution of Pearson's coefficient (*r*) between detrended annual MTE-WUE and WI series, (b) boxplot of Pearson's coefficient between detrended annual MTE-WUE and WI for each biome, (c) boxplot of Pearson's coefficient between detrended annual MTE-WUE and AI for each climate zone. The background colours in (b) indicate different climate zones (red: arid zone; yellow: semi-arid/sub-humid zone; green: humid zone). The interpretation of the boxplots is given in Figure 2. Map was drawn using ArcMap 10.2 and boxplots were drawn using R 3.1.2.



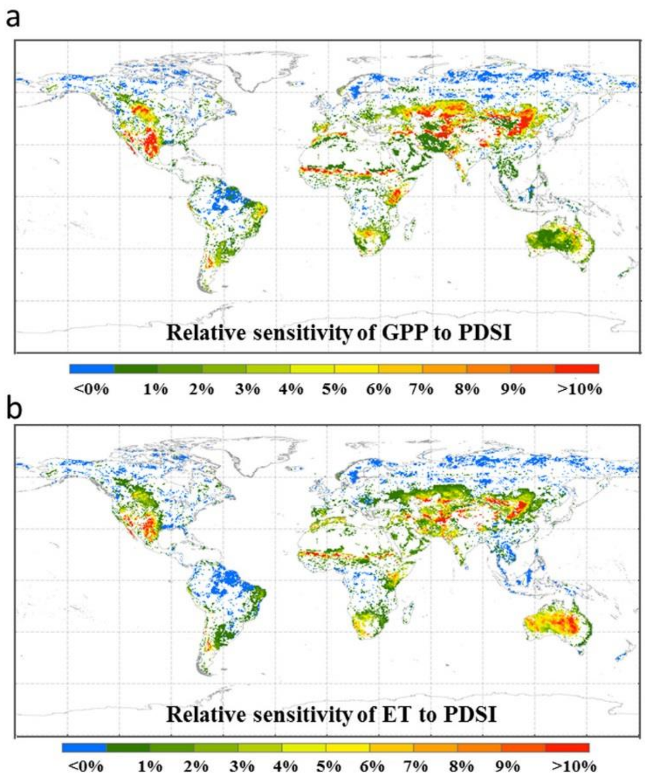
Supplementary Figure S5 Relationship between non-detrended annual MTE-WUE and WI series over 1982-2011. (a) Spatial distribution of Pearson's coefficient (*r*) between non-detrended annual MTE-WUE and WI series, (b) boxplot of Pearson's coefficient between non-detrended annual MTE-WUE and WI for each biome, (c) boxplot of Pearson's coefficient between non-detrended annual MTE-WUE and WI for each climate zone. The background colours in (b) indicate different climate zones (red: arid zone; yellow: semi-arid/sub-humid zone; green: humid zone). The interpretation of the boxplots is given in Figure 2. Map was drawn using ArcMap 10.2 and boxplots were drawn using R 3.1.2.

Supplementary Table S1 Descriptions of the flux sites used in this study including site number, site identifier (Site ID), latitude (Lat), Longitude (Lon), mean wetness index during the data period (Mean WI), climate zone (based on Mean WI), correlation coefficient between annual WUE and WI (*r*) and the *p*-value, and references (Ref).

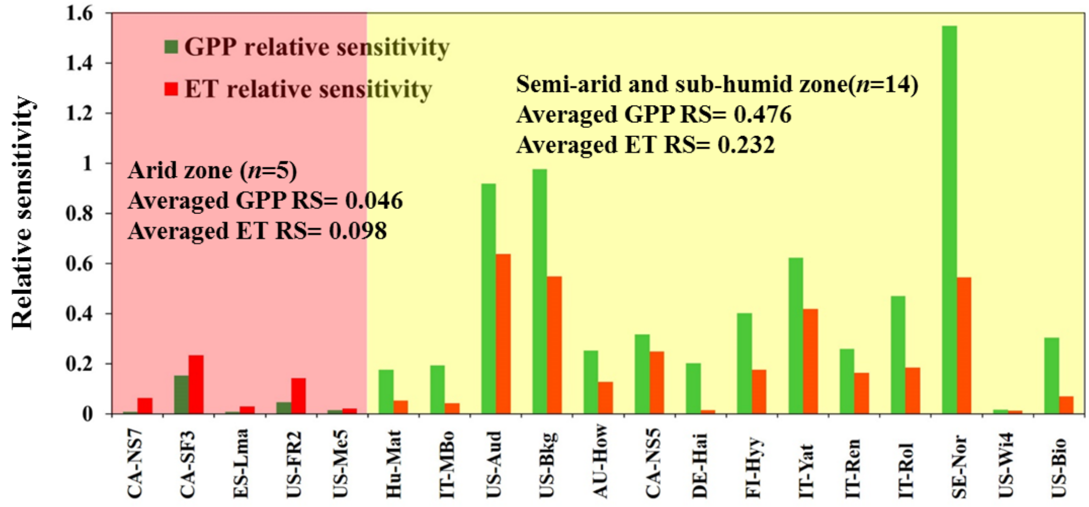
Site Number	Site ID	Lat (ºN)	Lon (ºE)	Biome Type	Mean WI	Climate Zone	*r*	*p*-value	Ref
1	BW-Ma1	-19.92	23.56	Savanna	0.07	Arid	-0.748	0.462	2
2	CA-NS1	55.88	-98.48	Shrub	0.11	Arid	-0.955	0.191	3
3	CA-NS3	55.91	-98.38	ENF	0.12	Arid	0.413	0.489	3
4	CA-NS6	55.92	-98.96	Shrub	0.16	Arid	0.329	0.671	3
5	CA-NS7	56.64	-99.95	Shrub	0.16	Arid	-0.989	0.096	4
6	CA-SF3	54.09	-106.00	Shrub	0.11	Arid	-0.999	0.027	5
7	ES_Lma	39.94	-5.77	Shrub	0.18	Arid	-0.998	0.037	6
8	US-FR2	29.95	-98.00	Savanna	0.12	Arid	-0.995	0.064	7
9	US-SRM	31.82	-110.87	Savanna	0.09	Arid	-0.546	0.642	8
10	US-Wkg	31.74	-109.94	Grass	0.07	Arid	-0.337	0.781	9
11	US_Me5	44.44	-121.57	Savanna	0.15	Arid	-0.994	0.07	10
12	AU-Tum	-35.66	148.15	EBF	0.57	Sub-humid	0.104	0.868	11
13	AU-How	-12.49	131.15	Savanna	0.43	Semi-arid	0.937	0.019	12
14	BE_Vie	50.31	6.00	MF	0.54	Sub-humid	0.228	0.556	13
15	CA-Man	55.88	-98.48	ENF	0.21	Semi-arid	0.394	0.44	14
16	CA-Mer	45.41	-75.52	Wetland	0.50	Sub-humid	0.608	0.184	15
17	CA-NS2	55.91	-98.52	ENF	0.21	Semi-arid	0.436	0.566	3
18	CA-NS5	55.86	-98.49	ENF	0.22	Semi-arid	0.928	0.0721	3
19	CA-Qfo	49.69	-74.34	ENF	0.64	Sub-humid	0.567	0.433	16
20	CA-SF2	54.25	-105.88	ENF	0.21	Semi-arid	0.034	0.978	5
21	DE_Geb	51.10	10.91	Crop	0.58	Sub-humid	-0.043	0.973	17
22	DE_Hai	51.08	10.45	DBF	0.53	Sub-humid	0.866	0.012	18
23	DE_Kli	50.89	13.52	Crop	0.45	Semi-arid	0.784	0.426	19
24	DE-Tha	50.96	13.57	ENF	0.52	Sub-humid	0.504	0.138	20
25	ES_ES1	39.35	-0.32	ENF	0.22	Semi-arid	0.287	0.5	21
26	ES_ES2	39.28	-0.32	Crop	0.22	Semi-arid	-0.238	0.847	21
27	ES_VDA	42.15	1.45	Grass	0.58	Sub-humid	0.325	0.789	22
28	FI-Hyy	61.85	24.29	ENF	0.31	Semi-arid	0.754	0.031	23
29	FR-LBr	44.72	-0.77	ENF	0.38	Semi-arid	0.244	0.56	24
30	FR_Pue	43.74	3.60	EBF	0.40	Semi-arid	-0.132	0.777	25
31	FR-Hes	48.67	7.06	DBF	0.51	Sub-humid	-0.251	0.551	26
32	HU_Bug	46.69	19.60	Grass	0.28	Semi-arid	0.476	0.424	27
33	HU_Mat	47.85	19.73	Grass	0.31	Semi-arid	0.994	0.069	27
34	IL-Yat	31.34	35.05	ENF	0.25	Semi-arid	0.952	0.048	28
35	IT_LMa	45.58	7.15	Grass	0.27	Semi-arid	0.644	0.167	29
36	IT_PT1	45.20	9.06	DBF	0.32	Semi-arid	0.951	0.2	30
37	IT_Ren	46.59	11.43	ENF	0.49	Semi-arid	0.951	0.085	31
38	IT_Sro	43.73	10.28	ENF	0.28	Semi-arid	-0.425	0.401	32
39	IT-Amp	41.90	13.61	Grass	0.42	Semi-arid	0.619	0.266	22
40	IT-Cpz	41.71	12.38	EBF	0.31	Semi-arid	-0.152	0.7	33
41	IT-MBo	46.02	11.05	Grass	0.55	Sub-humid	0.944	0.056	34
42	IT-Ro1	42.41	11.93	DBF	0.28	Semi-arid	0.809	0.024	35
43	IT-Ro2	42.39	11.92	DBF	0.31	Semi-arid	0.362	0.764	36
44	NL-Ca1	51.97	4.93	Grass	0.45	Semi-arid	0.714	0.286	37
45	PT-Esp	38.64	-8.60	EBF	0.22	Semi-arid	0.751	0.459	38

46	RU-Fyo	56.46	32.92	ENF	0.41	Semi-arid	0.052	0.912	39
47	SE-Fla	64.11	19.46	ENF	0.33	Semi-arid	0.191	0.809	40
48	SE-Nor	60.09	17.48	ENF	0.40	Semi-arid	0.809	0.1	41
49	UK-Esa	55.91	-2.86	Crop	0.31	Semi-arid	0.482	0.68	42
50	UK-Gri	56.61	-3.80	ENF	0.57	Sub-humid	0.94	0.005	43
51	US-Wi4	46.74	-91.16	MF	0.24	Semi-arid	0.993	0.067	44
52	US-ARM	36.61	-97.49	Crop	0.22	Semi-arid	-0.322	0.688	45
53	US-Aud	31.59	-110.51	Grass	0.31	Semi-arid	0.81	0.1	46
54	US-Bkg	44.35	-96.84	Grass	0.37	Semi-arid	0.995	0.064	47
55	US-Blo	38.90	-120.63	ENF	0.35	Semi-arid	0.654	0.056	48
56	US-Bo1	40.01	-88.29	Crop	0.38	Semi-arid	-0.331	0.35	49
57	US-FPe	48.31	-105.10	Grass	0.38	Semi-arid	0.431	0.469	47
58	US-Ha1	42.54	-72.17	DBF	0.55	Sub-humid	0.392	0.233	50
59	US-Ho1	45.20	-68.74	ENF	0.43	Semi-arid	0.07	0.859	51
60	US-Me2	44.45	-121.56	ENF	0.25	Semi-arid	0.635	0.562	52
61	US-MMS	39.32	-86.41	DBF	0.39	Semi-arid	0.516	0.484	53
62	US-Ne1	41.17	-96.48	Crop	0.28	Semi-arid	0.726	0.276	54
63	US-Ne3	41.18	-96.44	Crop	0.24	Semi-arid	0.083	0.917	54
64	US-Ton	38.43	-120.97	Savanna	0.22	Semi-arid	0.446	0.376	55
65	US-UMB	45.56	-84.71	DBF	0.31	Semi-arid	0.564	0.322	56
66	US-Var	38.41	-120.95	Grass	0.50	Semi-arid	-0.072	0.892	55
67	US-WCr	45.81	-90.08	DBF	0.45	Semi-arid	0.433	0.271	57
68	US_Bar	44.06	-71.29	DBF	0.53	Sub-humid	0.578	0.607	58
69	US_IB2	41.81	-88.24	Crop	0.56	Sub-humid	0.319	0.681	59
70	US_NR1	40.03	-105.55	ENF	0.26	Semi-arid	0.38	0.312	60
71	US_SP3	29.75	-82.16	EBF	0.43	Semi-arid	0.763	0.11	61
72	US_SP1	29.74	-82.22	EBF	0.34	Semi-arid	-0.097	0.903	61
73	US_Ro1	44.71	-93.09	Crop	0.51	Sub-humid	0.718	0.49	62
74	US_Ro3	44.72	-93.09	Crop	0.46	Semi-arid	0.771	0.439	62
75	US_So4	33.37	-116.62	Savanna	0.36	Semi-arid	0.859	0.343	63
76	US-Syv	46.24	-89.35	MF	0.31	Semi-arid	0.187	0.813	64
77	AT-Neu	47.12	11.32	Grass	1.15	Humid	-0.335	0.665	65
78	BE_Bra	51.31	4.52	MF	0.66	Humid	0.427	0.291	66
79	CA-Qcu	49.27	-74.04	ENF	0.70	Humid	-0.573	0.313	16
80	CH-Oe1	47.29	7.73	Grass	0.78	Humid	0.202	0.798	67
81	DE_Meh	51.28	10.66	Grass	0.68	Humid	-0.555	0.62	68
82	DE-Wet	50.45	11.46	ENF	0.69	Humid	0.192	0.757	69
83	FI_Kaa	69.14	27.30	Wetland	0.75	Humid	-0.331	0.52	70
84	FI_Sod	67.36	26.64	ENF	0.70	Humid	-0.31	0.55	71
85	FR_Lq1	45.64	2.74	Grass	1.11	Humid	-0.175	0.888	22
86	FR_Lq2	45.64	2.74	Grass	1.09	Humid	-0.008	0.995	22
87	IE_Ca1	52.86	-6.92	Crop	0.73	Humid	0.036	0.997	72
88	IE_Dri	51.99	-8.75	Grass	0.88	Humid	0.965	0.168	73
89	IT_Non	44.69	11.09	DBF	0.72	Humid	-0.488	0.512	74
90	NL-Loo	52.17	5.74	ENF	0.68	Humid	0.108	0.752	75
91	SE-Deg	64.18	19.56	Grass	0.78	Humid	0.671	0.251	76
92	US_SP2	29.76	-82.24	Savanna	0.65	Humid	-0.252	0.63	62
93	US-Goo	34.25	-89.87	Grass	0.89	Humid	0.405	0.499	77
94	US-PFa	45.95	-90.27	MF	1.04	Humid	0.345	0.503	78
95	VU-Coc	-15.44	167.19	EBF	0.73	Humid	0.505	0.495	79

Section 3 Relative sensitivity of GPP and ET to drought

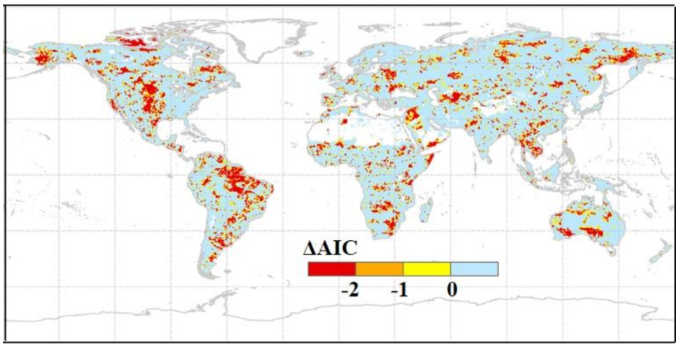


Supplementary Figure S6 Spatial distribution of relative sensitivity of annual (a) GPP and (b) ET to changes in PDSI based on detrended MTE data. Results show that the higher GPP sensitivity is generally located in global semi-arid and sub-humid regions (i.e., the Great Plain of North America, Northern Mexico, western part to the Pampas Steppe, south-eastern part to the Amazon Basin, mid-latitude of Euro-Asia, and the areas surrounding the Congo Basin) and higher ET sensitivity in global arid regions (i.e., the mid- and eastern Asia, south-eastern corner of Africa and majority of central- and western Australia). Our results also show a negative relationship between GPP (or ET) and PDSI in global energy-limited environments (i.e., tropical rainforests and boreal ecosystems). Maps were drawn using ArcMap 10.2.



Supplementary Figure S7 Relative sensitivities of GPP and ET to changes in wetness index at 19 flux sites (site detail is provided in Table S1), at which the WUE-WI relationship are significant (p<0.1). Results show that the five arid sites have a higher ET sensitivity and the 14 sites located in semi-arid/sub-humid regions exhibit a higher GPP sensitivity. The background colours indicate different climate zones (red: arid zone; yellow: semi-arid/sub-humid zone). Image was drawn using Excel 2013.

Section 4. Memory effect of previous-year drought on ecosystem WUE



Supplementary Figure S8 Spatial distribution of the difference between the Akaike Information Criterion value (ΔAIC) of the WUE model using the two-year PDSI and that using the one-year PDSI. The new model (with two-year PDSI) is considered as an improvement over the old one (with one-year PDSI) if the AIC value reduced by more than 2.0 (i.e., ΔAIC< -2). Map was drawn using ArcMap 10.2.

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