

Supplementary Information

Table S1

Aridity index for each site, and the regression slope of site-level correlations of the start of the growing season (SOS) with the growth rate (GR), sum of shortwave radiation (SR), mean air temperature (Ta) and mean soil water content (SWC) during the green-up period. The value with a significant correlation ($P < 0.05$) between two variables with significant values is in bold.

No.	Site name	IGBP	Aridity index	Slope (GR ~ SOS)	Slope (SR ~ SOS)	Slope (Ta ~ SOS)	Slope (SWC ~ SOS)
1	Acadia	DBF	1.37	0.28	-0.30	0.77	-0.25
2	Alligatorriver	DBF	0.96	0.31	-0.28	0.37	0.31
3	Arbutuslake	DBF	1.21	0.60	-0.63	0.20	0.42
4	Bartlett	DBF	1.28	-0.12	0.11	0.58	0.13
5	Bartlettir	DBF	1.28	0.53	-0.29	0.80	-0.32
6	Bostoncommon	DBF	0.89	0.63	-0.40	0.47	-0.26
7	Dollysods	DBF	1.19	0.23	-0.33	-0.43	-0.07
8	Harvard	DBF	1.10	0.12	0.06	0.65	0.10
9	Harvardbarn	DBF	1.11	0.20	0.29	0.50	-0.27
10	Harvardhemlock	DBF	1.11	-0.05	0.02	0.03	0.09
11	Joycekilmer	DBF	1.49	-0.03	0.53	0.55	-0.52
12	Mammothcave	DBF	0.98	0.17	-0.09	0.17	0.21
13	Missouriozarks	DBF	0.74	0.04	0.33	0.68	-0.68
14	Morganmonroe	DBF	0.93	0.53	-0.69	0.42	0.25
15	Nationalcapital	DBF	0.74	0.76	-0.49	0.34	0.53
16	Northattleboroma	DBF	1.04	0.01	0.21	0.57	-0.41
17	Oakridge2	DBF	0.98	-0.04	0.30	-0.75	-0.41
18	Proctor	DBF	1.31	0.35	-0.10	0.71	-0.08
19	Readingma	DBF	0.95	0.54	-0.65	0.19	-0.23
20	Shiningrock	DBF	1.51	0.20	-0.17	0.36	0.10
21	Smokylook	DBF	1.13	0.35	-0.22	0.32	-0.32
22	Smokypurchase	DBF	1.50	0.78	-0.63	0.12	-0.21
23	Snakerivermn	DBF	0.77	0.58	-0.72	-0.24	0.45
24	Thompsonfarm2	DBF	0.96	0.51	-0.56	0.54	0.02
25	Turkeypointdbf	DBF	0.99	0.92	-0.71	-0.06	0.22
26	Willowcreek	DBF	0.92	0.33	-0.46	0.19	0.50
27	Canadaobs	ENF	0.57	0.97	-0.94	0.03	0.52
28	Harvardbarn	ENF	1.11	0.06	0.05	0.69	0.01
29	Howland1	ENF	1.12	-0.09	-0.11	0.61	-0.07
30	Missouriozarks	ENF	0.74	-0.37	0.22	0.80	-0.74
31	Oregonmp	ENF	0.70	0.77	-0.70	0.68	-0.30
32	Thompsonfarm2N	ENF	0.96	0.46	-0.57	0.06	0.64

33	Turkeypointenf39	ENF	1.00	0.76	−0.46	0.75	0.10
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Figure S1

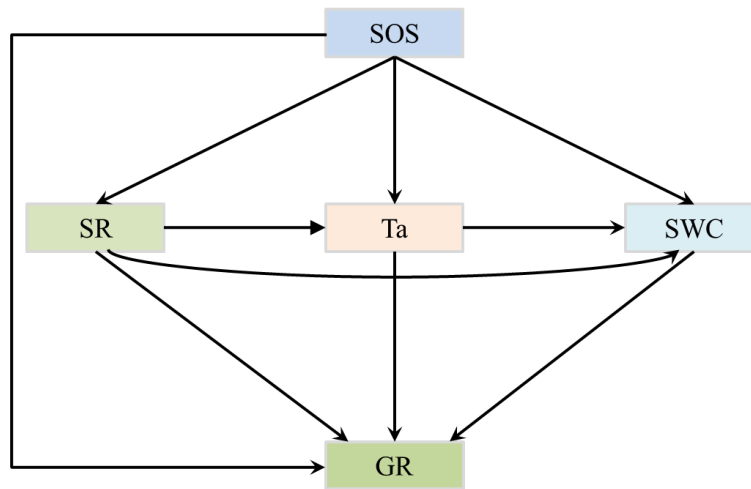


Figure S1. The initial structural equation model. All plausible pathways based on theoretical and empirical predictions were considered. SOS: start of growing season, SR: sum of shortwave radiation during the green-up period, Ta: mean air temperature during the green-up period, SWC: mean soil water content during the green-up period, GR: growth rate during the green-up period.

Figure S2

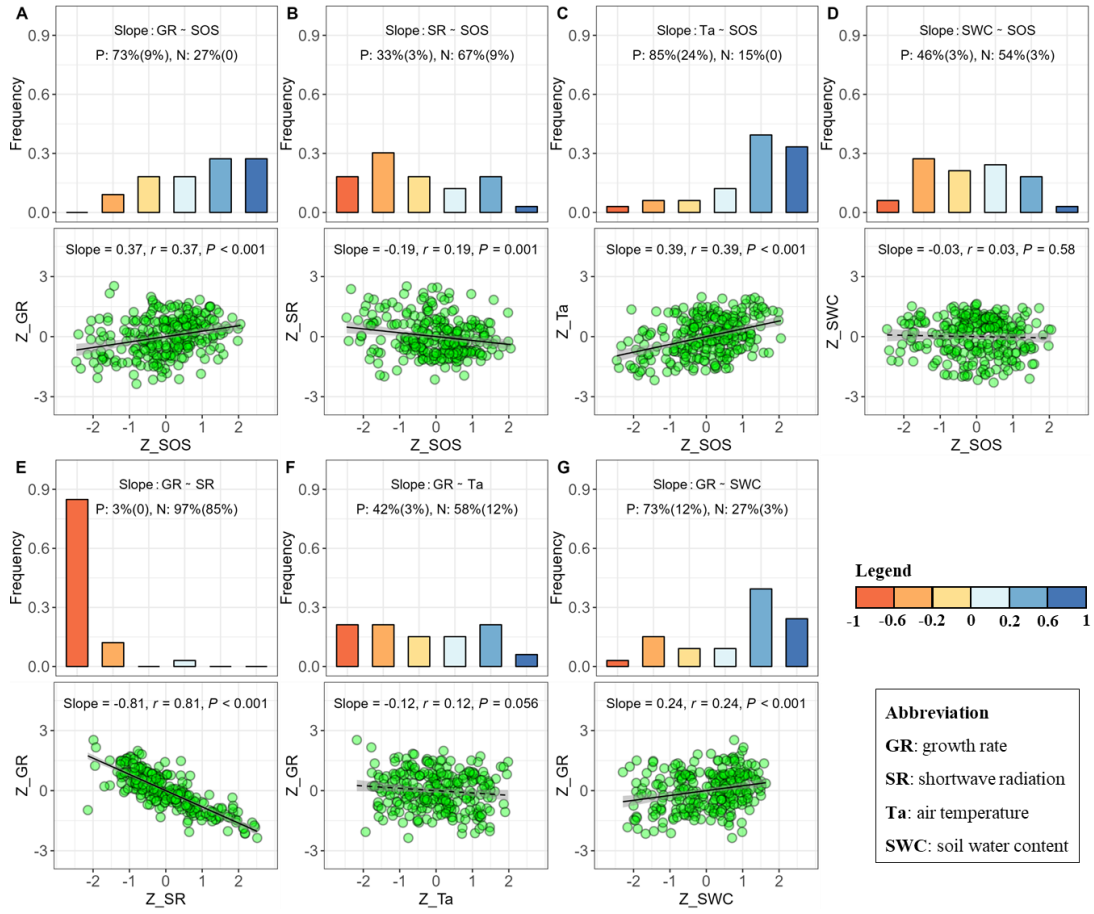


Figure S2. Frequency distributions and overall regression of site-level correlations of the start of the growing season (SOS) with the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C) and mean soil water content (SWC, D) during the green-up period, and the GR with SR (E), Ta (F) and SM (G). The percentages of areas of positive correlation (P) and negative correlation (N) are shown, and the significant percentages are displayed in parentheses. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. The extraction of SOS was based on the threshold method of 30%.

Figure S3

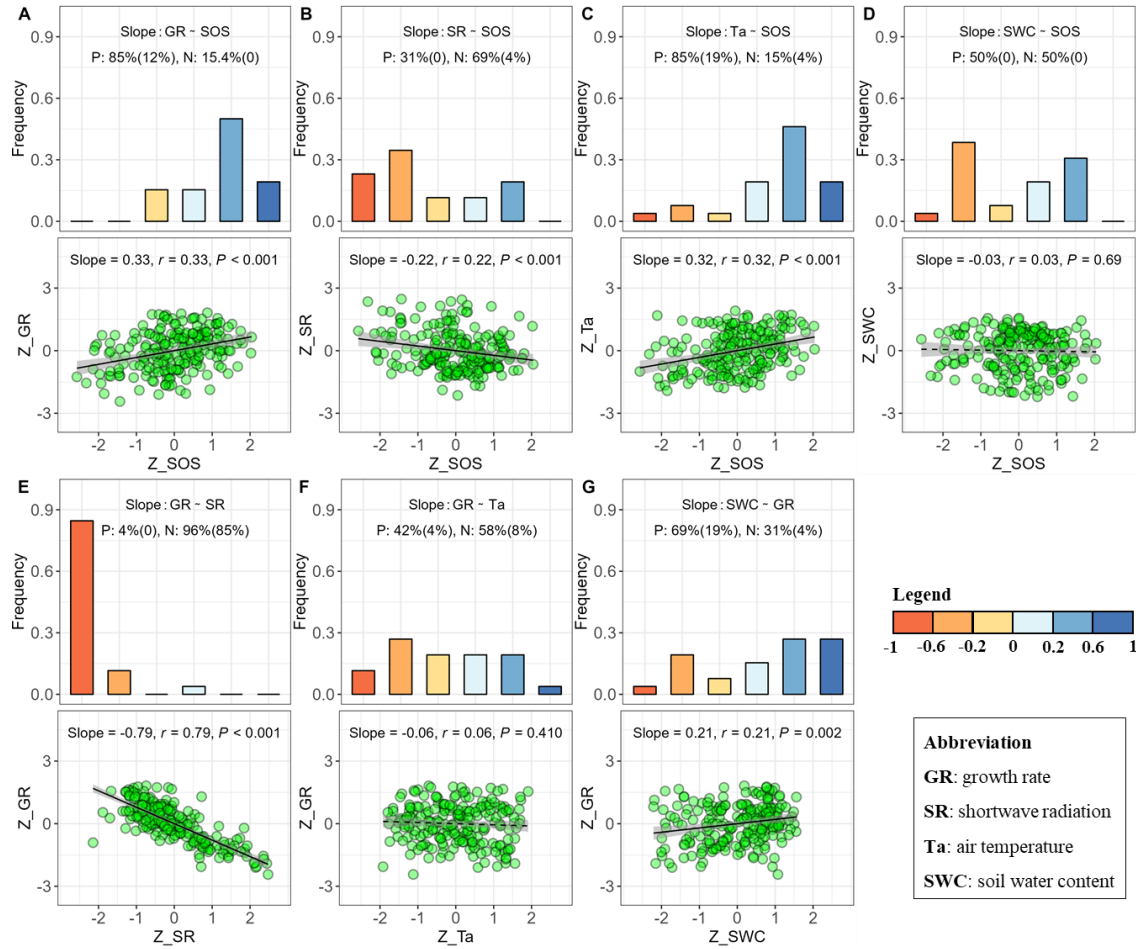


Figure S3. Frequency distributions and overall regression of site-level correlations of the start of the growing season (SOS) with the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C) and mean soil water content (SWC, D) during the green-up period, and the GR with SR (E), Ta (F) and SM (G) for deciduous broadleaf forests (DBF). The percentages of areas of positive correlation (P) and negative correlation (N) are shown, and the significant percentages are displayed in parentheses. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. The extraction of SOS was based on the threshold method of 20%.

Figure S4

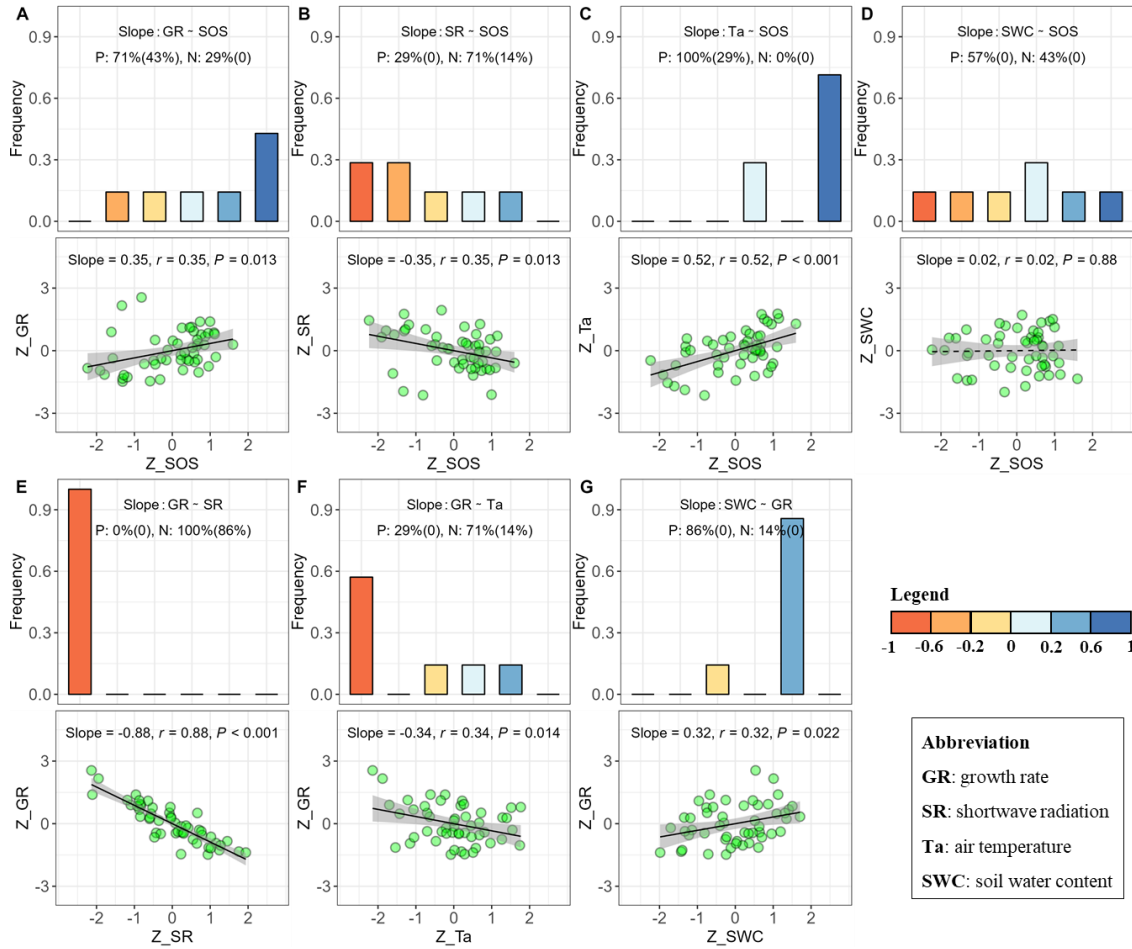


Figure S4. Frequency distributions and overall regression of site-level correlations of the start of the growing season (SOS) with the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C) and mean soil water content (SWC, D) during the green-up period, and the GR with SR (E), Ta (F) and SM (G) for evergreen needleleaf forests (ENF). The percentages of areas of positive correlation (P) and negative correlation (N) are shown, and the significant percentages are displayed in parentheses. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. The extraction of SOS was based on the threshold method of 20%.

Figure S5

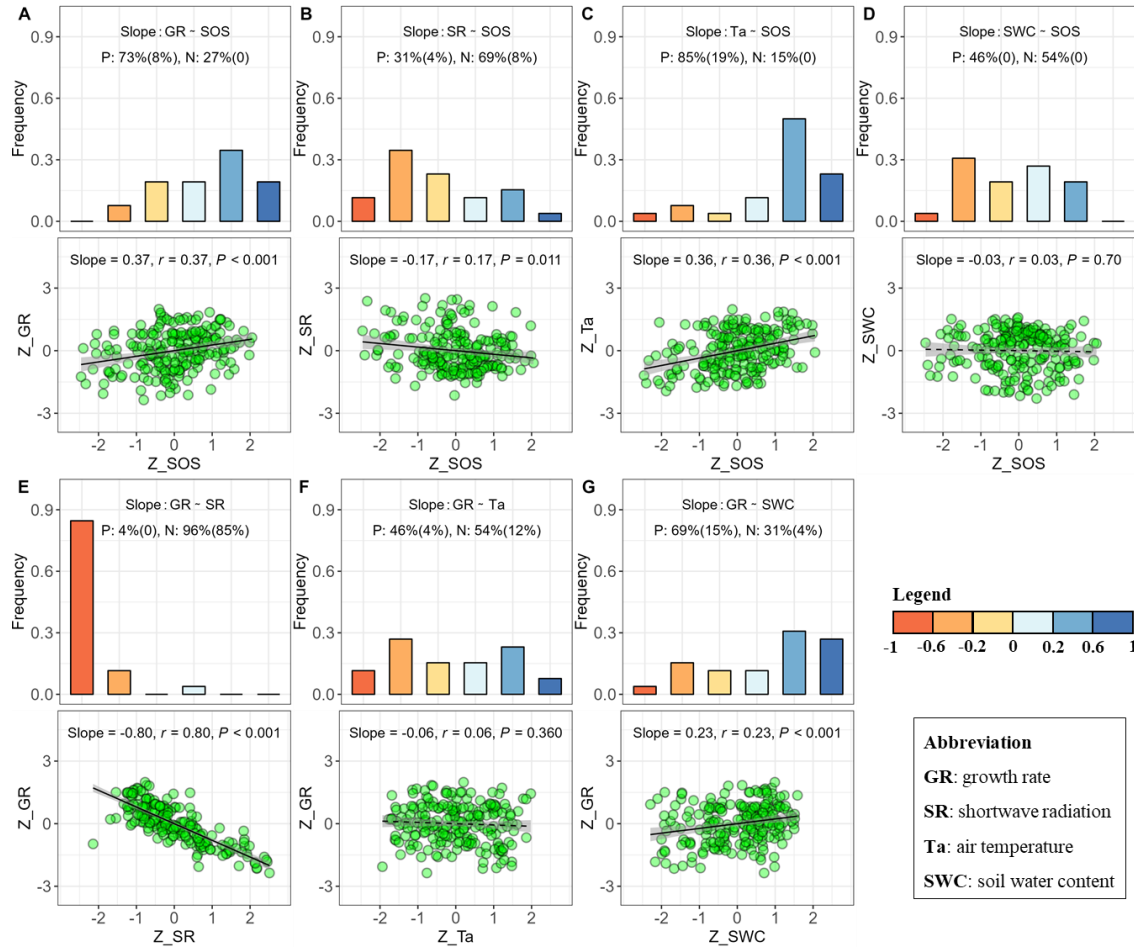


Figure S5. Frequency distributions and overall regression of site-level correlations of the start of the growing season (SOS) with the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C) and mean soil water content (SWC, D) during the green-up period, and the GR with SR (E), Ta (F) and SM (G) for deciduous broadleaf forests (DBF). The percentages of areas of positive correlation (P) and negative correlation (N) are shown, and the significant percentages are displayed in parentheses. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. The extraction of SOS was based on the threshold method of 30%.

Figure S6

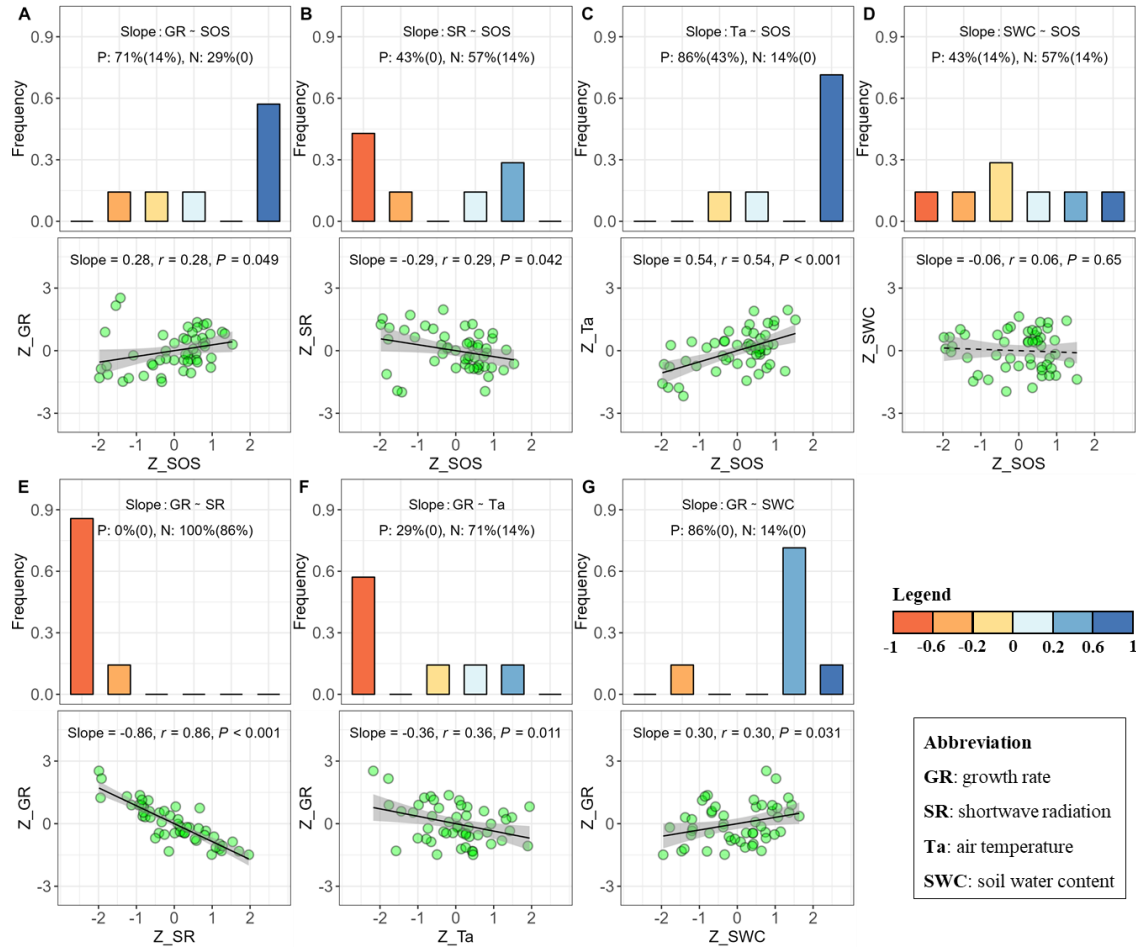


Figure S6. Frequency distributions and overall regression of site-level correlations of the start of the growing season (SOS) with the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C) and mean soil water content (SWC, D) during the green-up period, and the GR with SR (E), Ta (F) and SM (G) for evergreen needleleaf forests (ENF). The percentages of areas of positive correlation (P) and negative correlation (N) are shown, and the significant percentages are displayed in parentheses. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. The extraction of SOS was based on the threshold method of 30%.

Figure S7

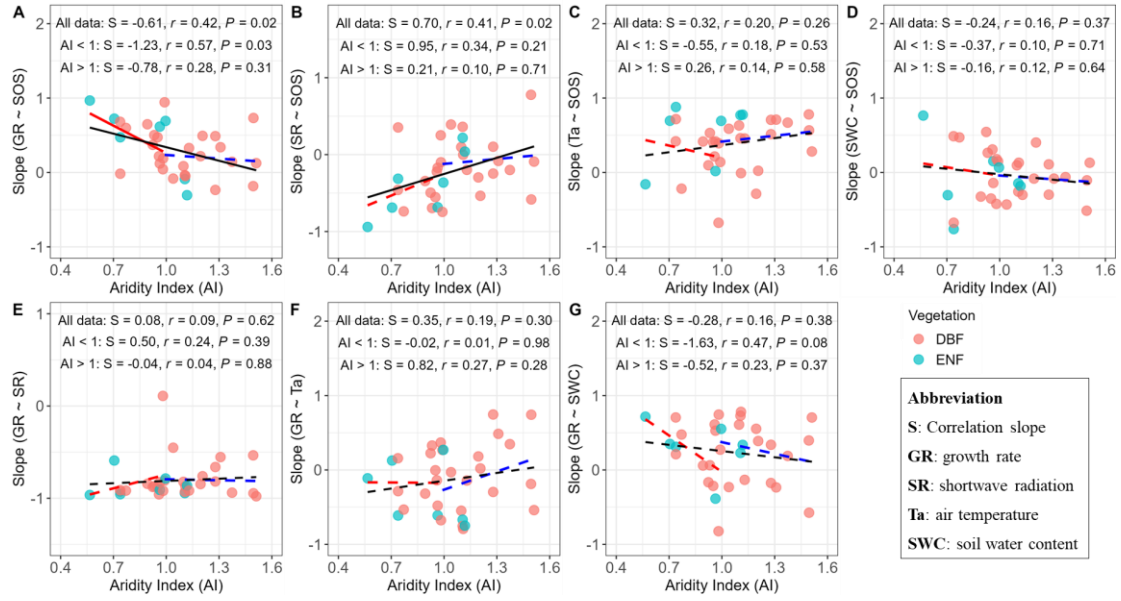


Figure S7. Changes in site-level slopes of the growth rate (GR, A), sum of shortwave radiation (SR, B), mean air temperature (Ta, C), mean soil water content (SWC, D) during the green-up period, and the start of the growing season (SOS) with the aridity index, and site-level slopes of the SR (E), Ta (F), SM (G), and the GR with the aridity index. The results are derived from 268 year-site PhenoCam observations. The time-series data for each variable from each site were standardized using Z-scores. Lower aridity-index values correspond to drier climatic conditions. DBF, deciduous broadleaf forest; ENF, evergreen needleleaf forest. The extraction of SOS was based on the threshold method of 30%.

Figure S8

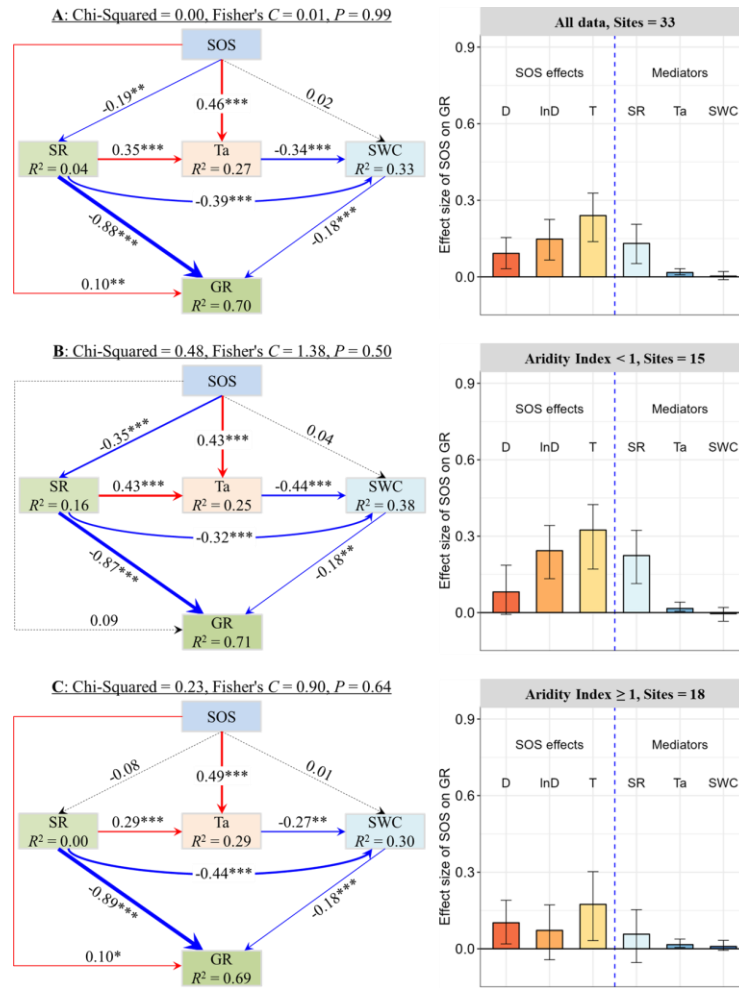


Figure S8. Structural equation models (SEMs) and the effect sizes of the start of the growing season (SOS) on vegetation growth rate (GR) through direct effects (SOS effects) and indirect effects via ‘mediator’ variables (mediators) for all data (A), the data with aridity index < 1 (B), and the data with aridity index ≥ 1 (C). D: direct effect; InD: indirect effect; T: total effect; SR: sum of shortwave radiation during the green-up period; Ta: mean air temperature during the green-up period; SWC: mean water content during the green-up period. The fitting parameters of SEMs are shown at the top of each SEM. The error bars in the histograms represent 95% confidence intervals. The solid line refers to a significant correlation between variables with $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***). The red and blue lines indicate positive and negative relationships, respectively. The dotted or black line indicates a non-significant correlation between variables. The thickness of the lines indicates the strength of the correlation. The time-series data for each variable from each pixel of the SIF data were standardized using Z-scores. Lower aridity index values correspond to more arid climate conditions and vice versa. The extraction of SOS was based on the threshold method of 30%.

Figure S9

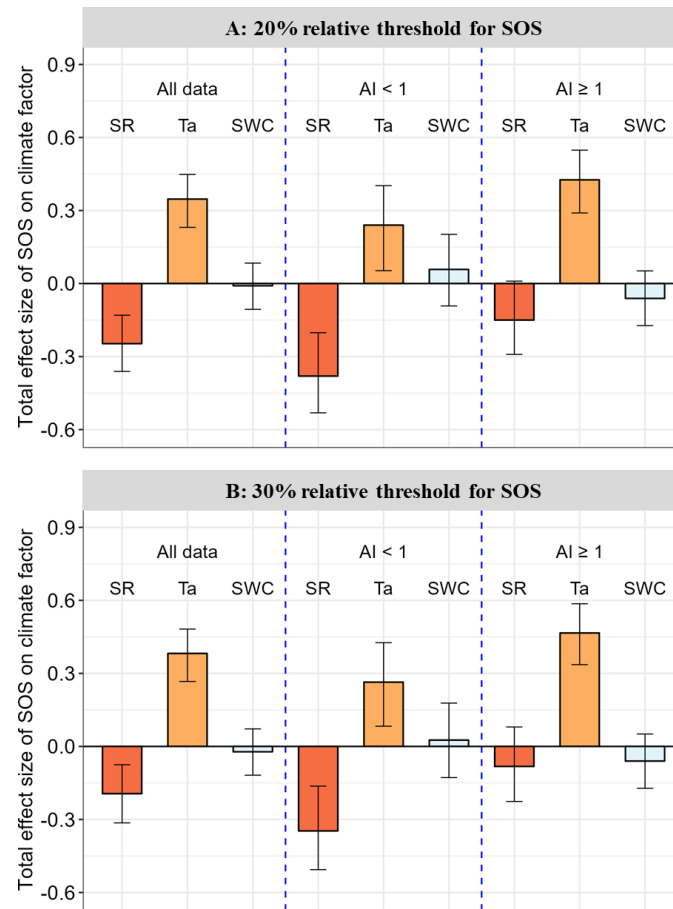


Figure S9. Total effect size of SOS on accumulative shortwave radiation (SR), mean air temperature (Ta), mean soil water content (SWC) during the green-up period for all data, the data with aridity index < 1, and the data with aridity index ≥ 1 based on the threshold method of 20% (A) and 30% (B). These results are derived from the structural equation models in Figures. 4 and S8. The error bars in the histograms represent 95% confidence intervals. Lower aridity-index values correspond to drier climatic conditions.