

Supplementary Materials

Figures

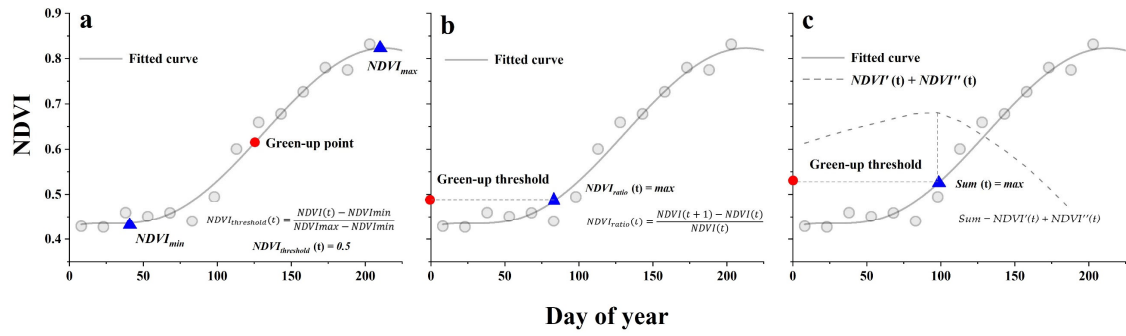


Figure S1. The theoretical curves of three methods for identifying the spring green-up date (GUD) in a single phenological year of an illustrative pixel.

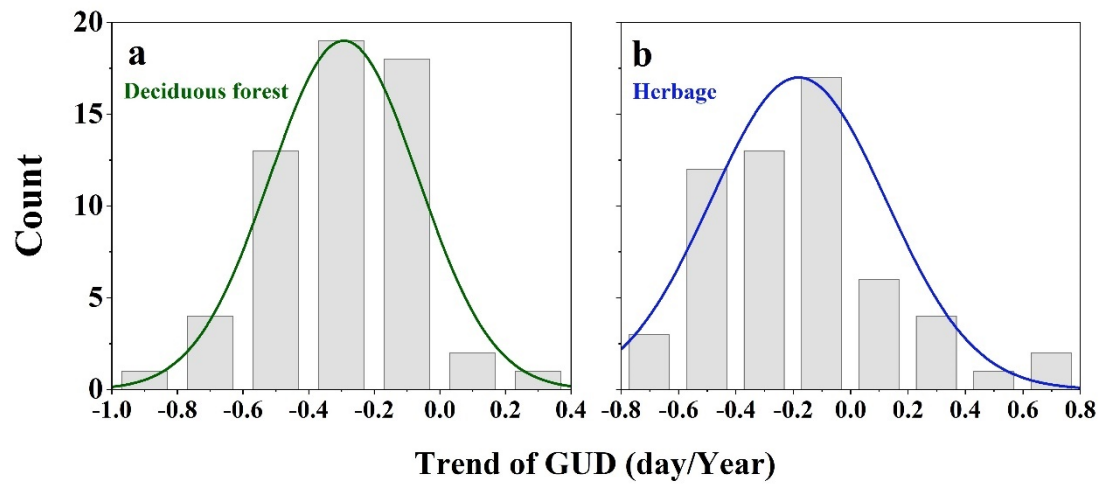


Figure S2. The trend of green-up dates (GUD) for deciduous forest (a) and herbages (b) in each forest-herbage-mixed (FHM) site over more than 25 years from 1982 to 2013.

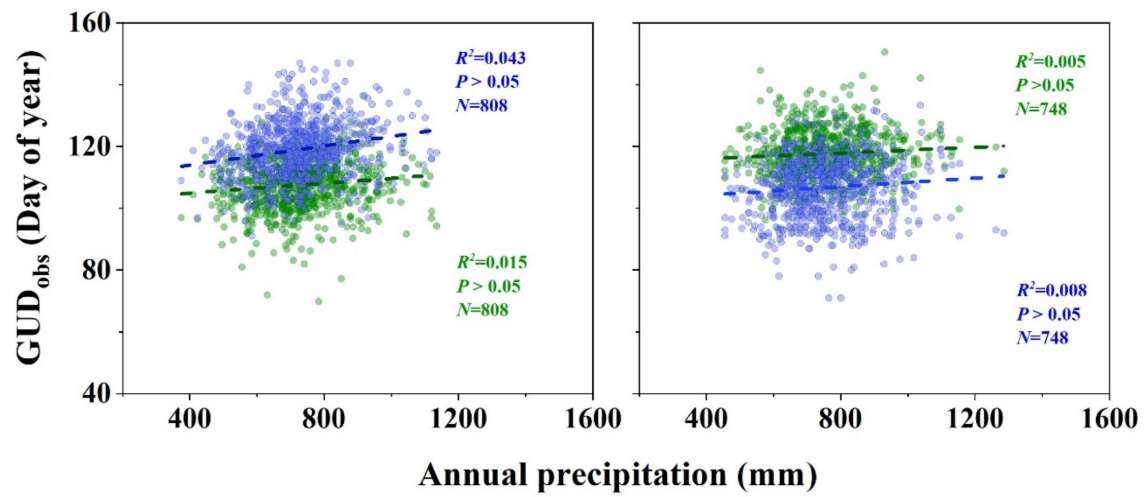


Figure S3. Relationships between annual observed green-up date (GUD_{obs}) of deciduous forest (green) and herbages (blue), and annual precipitation for all FHM sites with GUD_{obs-forest} < GUD_{obs-herbage} (a) and with GUD_{obs-herbage} < GUD_{obs-forest} (b).

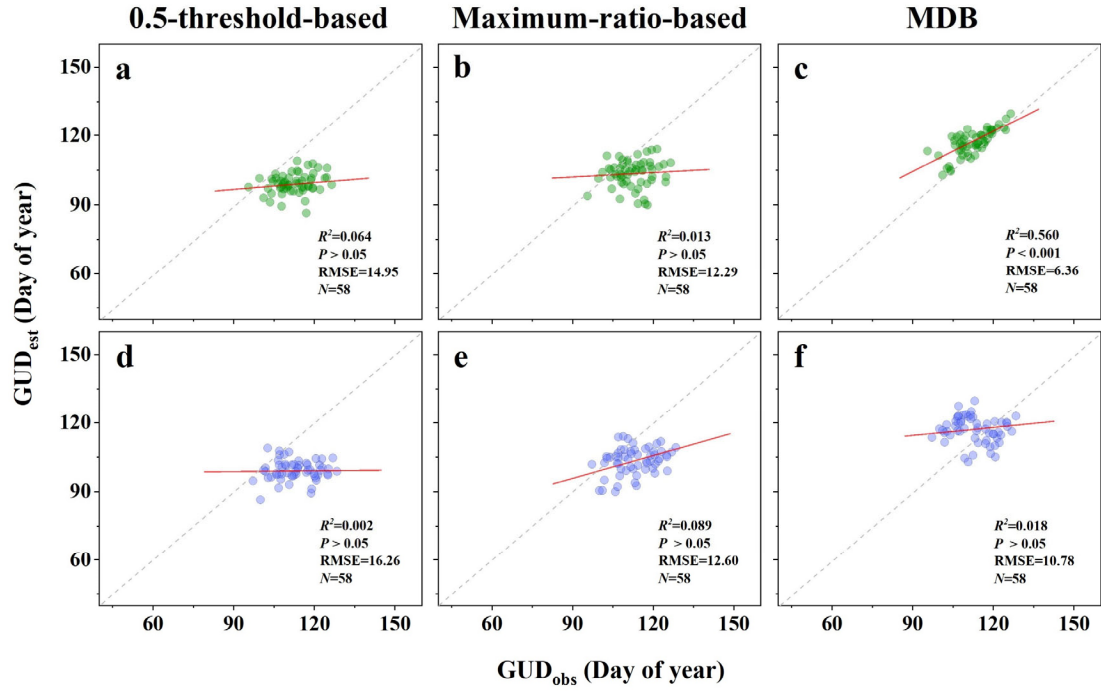


Figure S4. Comparisons between multi-years average observed green-up date (GUD_{obs}) of deciduous forest (green) and herbages (blue), and estimated green-up date (GUD_{est}) of three methods (0.5-threshold-based method, Maximum-ratio-based method and Maximum-derivative-based (MDB) method) for all FHM sites. The gray dashed line represents the 1:1 line, and the red lines are the regression lines. The root mean square error (RMSE) was also used to evaluate the predictive performance.

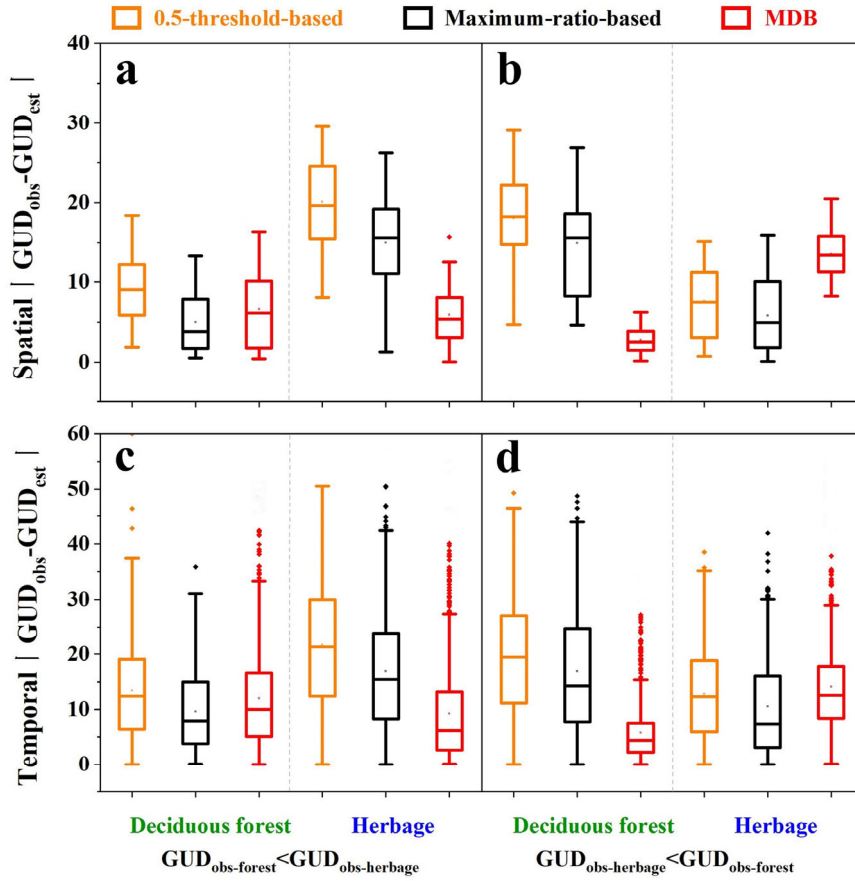


Figure S5. Comparisons of three predicted methods (0.5-threshold-based method, Maximum-ratio-based method and Maximum-derivative-based (MDB) method) for reproducing the spatial and temporal variations of green-up date (GUD) by using absolute differences between observed GUD of deciduous forest and herbage, and estimated GUD ($|GUD_{obs} - GUD_{est}|$) through all FHM sites with $GUD_{obs-forest} < GUD_{obs-herbage}$ and with $GUD_{obs-herbage} < GUD_{obs-forest}$.

Tables

Table S1 The forest-herbage-mixed (FHM) sites with $GUD_{\text{obs-forest}} < GUD_{\text{obs-herbage}}$ from the Pan European Phenology network (PEP725).

Country	Name	PEP_ID	Lon	Lat	Tem	Pre	Years	Dec_forest (%)	Herbage (%)	F+G (%)
Germany	KELLINGHUSEN	280	9.71667	53.95	9.48	782.23	25	30.27	32.56	93.59
Germany	KOENIGSFOERDE	402	9.26667	52.0667	9.41	739.21	25	21.95	64.77	93.12
Germany	UELZEN	790	10.5667	52.9667	9.39	644.74	27	29.14	32.18	80.81
Germany	GASTE	969	7.95	52.25	9.85	738.30	29	30.73	30.88	91.35
Germany	SCHLICH	1448	6.41667	50.8	9.67	969.14	27	28.13	57.01	93.50
Germany	STROMBERG	1524	8.2	51.8	9.81	747.53	28	24.66	64.87	96.62
Germany	ISINGDORF	1646	8.43333	52.05	9.51	759.52	25	24.12	45.32	92.50
Germany	BRENSBACH	1953	8.88333	49.7667	10.16	672.14	28	42.70	41.44	92.86
Germany	RIMHORN	1981	9.03333	49.7833	9.63	664.65	29	45.89	23.88	76.76
Germany	AUE	2055	10.1167	51.1833	8.50	673.92	25	50.10	29.49	92.00
Germany	JESTAEDT	2061	10.0167	51.2167	8.50	677.54	26	29.92	43.12	93.56
Germany	BERGEN-ENKHEIM	2351	8.75	50.15	9.89	673.96	27	27.36	32.95	94.42
Germany	GEBROTH	2521	7.65	49.8667	10.03	694.22	25	55.04	35.20	94.10
Germany	MONREAL	2531	7.16667	50.3	9.88	792.56	25	45.81	39.77	94.52
Germany	OBERBETTINGEN	2613	6.63333	50.2833	9.14	905.40	25	25.48	40.89	86.81
Germany	BORNICH	2672	7.75	50.1333	9.66	720.75	26	28.14	45.14	95.05
Germany	FREILINGEN	2690	7.83333	50.5667	9.60	776.12	26	35.28	28.90	83.70

Germany	GEHRWEILER	2820	7.76667	49.5833	10.07	690.82	30	34.87	55.34	96.98
Germany	OBERDERDINGEN	3023	8.8	49.0667	10.66	694.68	26	29.00	51.39	95.90
Germany	BRUCHSAL	3052	8.58333	49.1333	10.63	685.43	27	30.23	31.15	89.76
Germany	EGGENSTEIN	3099	8.38333	49.0833	10.99	695.54	31	33.58	26.69	81.37
Germany	HELMSTADT	3146	8.98333	49.3333	10.69	690.20	25	25.41	70.82	97.12
Germany	LAHR	3237	7.88333	48.3333	10.82	819.22	25	42.84	25.79	85.43
Germany	RINGINGEN	3381	9.81667	48.35	8.90	835.32	26	29.59	51.59	84.65
Germany	DEGGENDORF	3693	12.9667	48.8333	9.23	773.90	27	26.86	40.03	91.06
Germany	IHRLESTEIN	3738	11.8667	48.9333	8.79	710.60	26	45.95	14.63	71.29
Germany	HELDTRIT	4039	10.8	50.3667	8.79	612.78	27	23.57	46.55	86.25
Germany	KLEINBLITTERSDORF	4632	7.05	49.1667	10.06	725.80	31	34.09	29.15	94.90
Germany	LEBACH	4641	6.91667	49.4167	10.23	740.25	31	32.09	46.54	93.32
Germany	BRANDIS2	5659	12.6167	51.3333	9.77	528.90	28	23.65	47.18	87.88

Lon, longitude; *Lat*, latitude; *Tem*, multi-years average temperature; *Pre*, multi-year average precipitation; *Years*, number of years with record; *Dec_forest (%)*, the percentage of deciduous forest area in a grid zone with spatial resolution is 0.083 degree; *Herbage (%)*, the percentage of herbage area in a grid zone with spatial resolution is 0.083 degree; *F+G (%)*, the percentage of deciduous forest and herbage area to all vegetation area in a grid zone with spatial resolution is 0.083 degree.

Table S2 The forest-herbage-mixed (FHM) sites with $GUD_{\text{obs-herbage}} < GUD_{\text{obs-forest}}$ from the Pan European Phenology network (PEP725).

Country	Name	PEP_ID	Lon	Lat	Tem	Pre	Years	Dec_forest (%)	Herbage (%)	F+G (%)
Germany	IMMENSEN	598	10.0667	52.4	9.22	647.34	28	23.62	41.07	81.94
Germany	STELICHTE	640	9.53333	52.95	9.50	695.81	31	21.30	42.34	77.13
Germany	KALLENHARDT	1788	8.43333	51.45	8.62	845.50	26	37.46	23.80	72.06
Germany	WEIDENHAUSEN	1851	8.36667	51	9.13	763.53	26	48.65	26.29	72.68
Germany	EIFA	1906	9.33333	50.75	8.63	761.44	25	39.17	44.71	92.56
Germany	OBER-OHMEN	1911	9.11667	50.6167	8.55	756.22	25	29.63	47.73	96.30
Germany	RHODEN	2250	9.01667	51.4667	8.52	786.96	29	27.89	43.52	81.50
Germany	BRAUNFELS	2432	8.38333	50.5167	9.21	766.51	27	53.39	23.53	92.50
Germany	HONIGSESSEN	2485	7.75	50.8167	9.51	787.68	26	54.88	21.90	81.26
Germany	KERPEN	2608	6.73333	50.3	9.30	893.18	26	27.44	47.89	91.84
Germany	SINDELFINGEN	2879	9	48.7	9.81	694.83	26	32.67	27.42	91.43
Germany	RUECKERSHAGEN	2886	9.95	49.25	8.95	650.23	26	25.81	65.35	97.42
Germany	RUIT	2899	9.26667	48.7333	9.82	675.89	26	28.38	35.32	92.01
Germany	GERSTETTEN	2914	10.0167	48.6333	8.56	714.48	25	36.81	47.39	90.65
Germany	MOENSHEIM	2953	8.86667	48.8667	9.50	844.87	25	41.15	39.19	93.00
Germany	NELLINGEN	3019	9.8	48.55	8.36	763.01	25	21.85	68.50	94.80
Germany	ADELSHEIM	3065	9.4	49.4	10.05	641.51	27	30.24	53.16	93.32
Germany	BALINGEN	3346	8.85	48.2833	8.87	973.13	30	23.45	43.59	86.20
Germany	GENKINGEN	3422	9.2	48.4	8.58	938.47	29	51.08	36.42	93.82

Germany	GINDLKOFEN	3534	11.95	48.05	8.98	777.83	31	25.02	59.34	90.04
Germany	WOLNZACH	3617	11.6333	48.6	8.78	712.39	27	25.10	65.30	84.81
Germany	KALLMUENZ	3858	11.9667	49.1667	8.68	658.48	27	30.07	46.20	71.36
Germany	FURTHIMWALD	3865	12.85	49.3167	8.28	730.00	25	24.89	43.30	87.05
Germany	MUEHLHAUSEN	3884	11.45	49.1667	9.06	656.91	26	22.55	40.19	72.58
Germany	SCHOENACH	3937	12.4333	48.9167	8.83	730.70	25	25.92	71.35	95.32
Germany	SANDERSDORF	3945	11.6167	48.9	8.76	713.77	25	23.35	55.33	79.54
Germany	LIMBACH	4643	6.9	49.4667	10.14	734.07	26	55.22	30.25	94.42
Germany	OTZENHAUSEN	4664	7	49.6	9.48	777.53	28	58.68	24.05	80.20

Lon, longitude; *Lat*, latitude; *Tem*, multi-years average temperature; *Pre*, multi-year average precipitation; *Years*, number of years with record; *Dec_forest (%)*, the percentage of deciduous forest area in a grid zone with spatial resolution is 0.083 degree; *Herbage (%)*, the percentage of herbage area in a grid zone with spatial resolution is 0.083 degree; *F+G (%)*, the percentage of deciduous forest and herbage area to all vegetation area in a grid zone with spatial resolution is 0.083 degree.