Supplementary Effects of Different Methods on the Comparison between Land Surface and Ground Phenology—A Methodological Case Study from South-Western Germany

Gourav Misra, Allan Buras and Annette Menzel

Equation (S1) Weighted Gaussian filter: The Gaussian filter used in this study was designed such that the weights of each value contributing to the local value followed a typical Gaussian distribution i.e., the weights were distributed symmetrically around the central value, their sum added up to 1, and their fractional weights W_i were calculated using the following equation:

$$W_i = \frac{1}{0.5 * k * \sqrt{pi}} * \exp\left(\frac{-w_i^2}{(0.5 * k)^2}\right) \quad \text{(S1)}$$

With k being the size of the filter and w_i being the *i*th value in a sequence from −k to k. To achieve values which add up to 1, W_i has to be normalized by the sum of itself. For instance, when solving the equation for k = 1 and normalizing by its sum, we get weights of $W_{1:3}$ = 0.01766842; 0.96466316; 0.01766842 which add up to exactly 1. For this study we used k = 5.

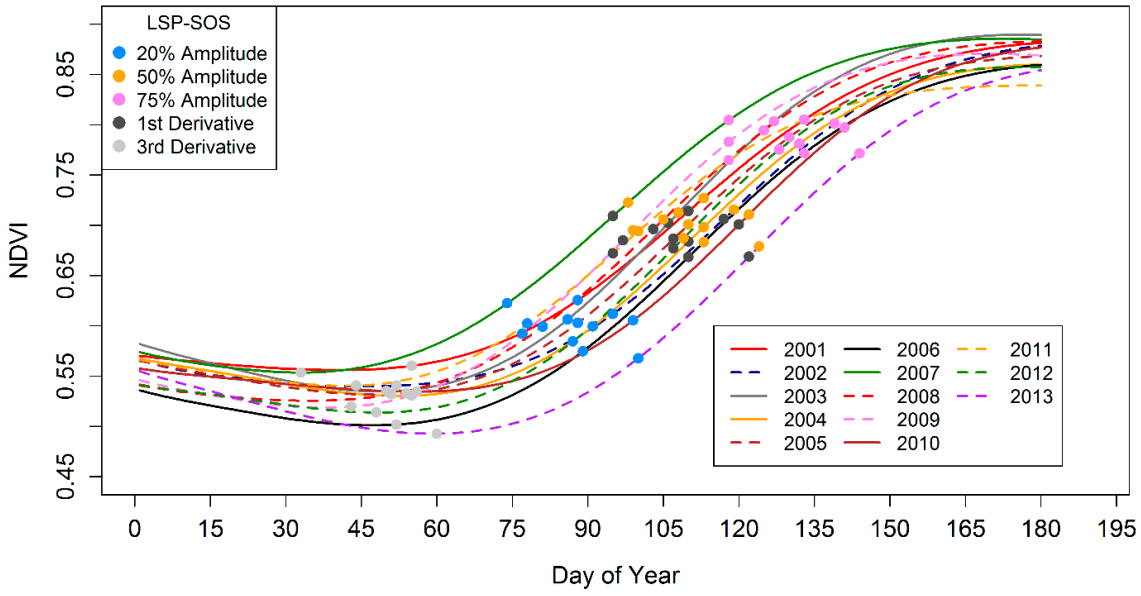

Figure S1. Gaussian smoothing results-I: An example of a few LSP-SOS obtained from different methods for various years indicates that each method corresponds to a particular part of the NDVI curve (time series is Gaussian smoothed). Methods such as 20% amplitude and 3rd derivative methods cover the early part of the growing season, whereas, 75% and 50% amplitudes, and 1st derivative cover the later part of the growing season.

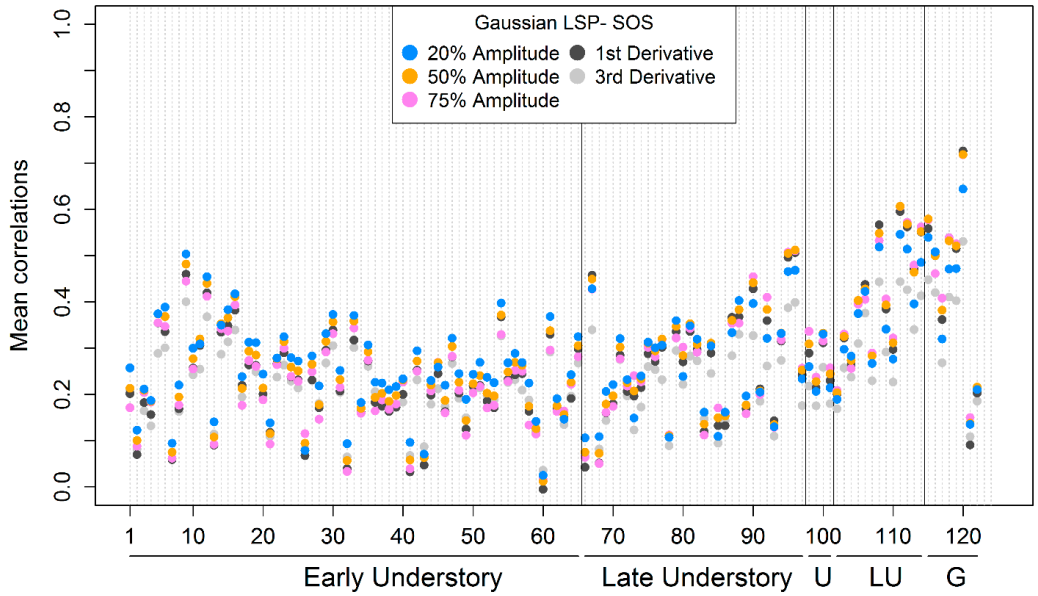

Figure S2. Gaussian smoothing results-II: Mean of Spearman's rank correlation coefficients between GP and selected LSP-SOS extraction methods for broadleaf pixels in study area. Note: species on the x-axis are grouped according to traits and arranged in order of increasing mean SOS (see Supplement S.8 for complete details of species). Note: Figure 6 in paper shows the individual correlations at pixel level for selected species such as *Myosotis sylvatica*, *Lathyrus niger* and *Fagus sylvatica* with species ID/No. 12, 95 and 119 respectively.

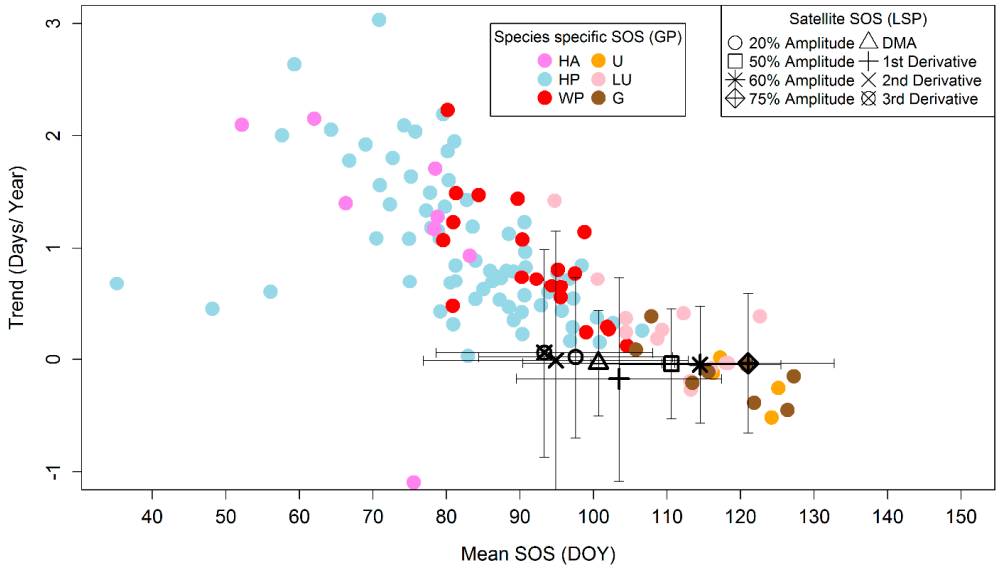

Figure S3. Double Log smoothing results-I: Comparison of LSP-SOS from Double Log smoothed NDVI (as special symbols in black) and various species-specific ground phenophases—GP (as filled and colored circles). Note: Ground phenophases codes: HA (herbaceous annuals), HP (herbaceous perennials) and WP (woody perennials) are understory leaf unfolding dates; U (Conifers leaf unfolding); and LU (leaf unfolding) and G (greening) for broadleaf species (see Supplement S1 for complete details of species specific information).

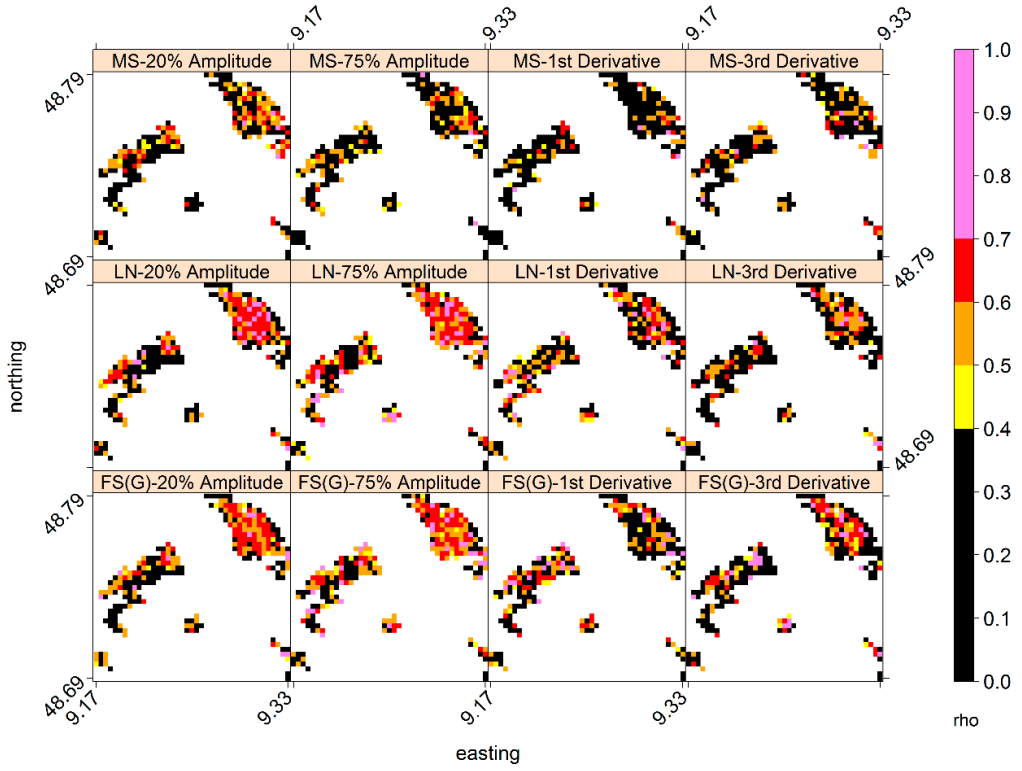

Figure S4. Double Log smoothing results-II: Maps showing Spearman's rank correlations ($p < 0.05$, one-tailed positive) between LSP (from Double Log smoothing) and GP for selected understory and broadleaf species. (MS-*Myosotis sylvatica* (leaf unfolding), LN-*Lathyrus niger* (leaf unfolding) and FG(G)-Fagus sylvatica (greening) with mean SOS of 70.46, 102.69 and 120.85 day of year respectively).

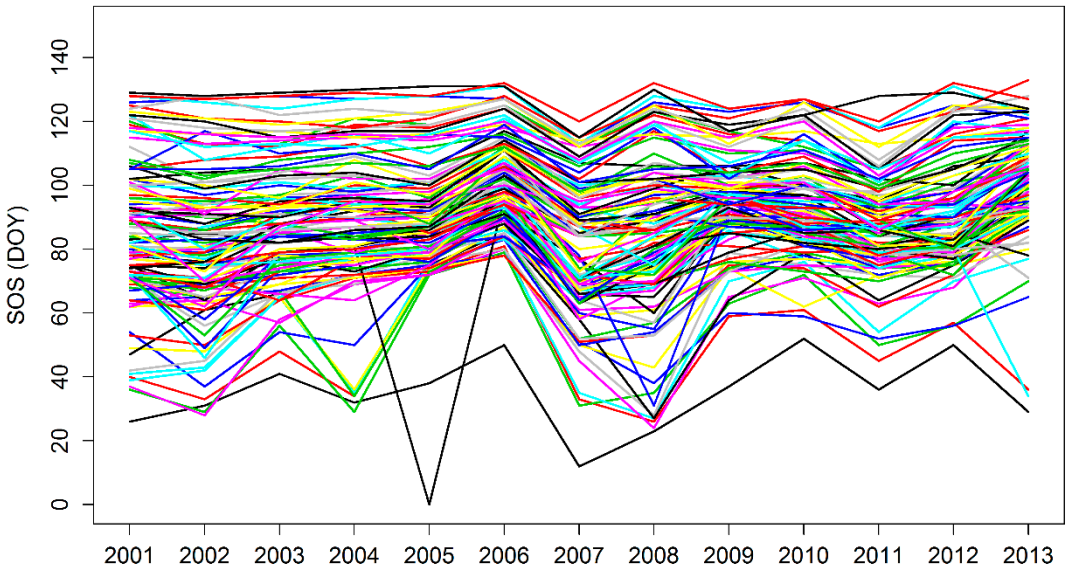

Figure S5. Time series of GP-SOS-I: Species specific GP-SOS time series. Note: The years 2007, 2009 and 2011 in GP show relatively early mean starts of season in the 2001–2013 time series which match strongly with the LSP-SOS estimates. The GP-SOS for various species are colored differently.

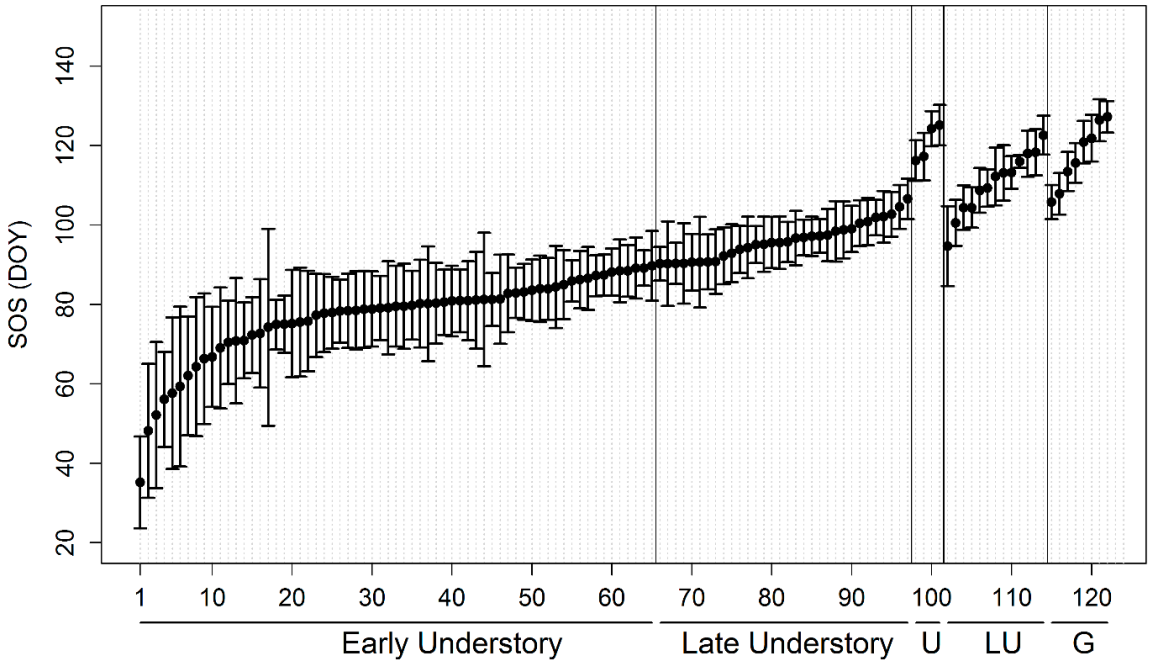

Figure S6. Time series of GP-SOS-II: GP-SOS time series with dark filled circles as mean GP-SOS of species, one standard deviation as error bars and the species No. are grouped according to traits in x-axis (for species IDs see Table S1). The inter-annual variance of SOS for species decreases as the season progresses i.e. the early understory SOS has a larger variance than broadleaf SOS. This difference is also evident in the various LSP-SOS methods where the 20% amplitude and 3rd derivative corresponding to early understory SOS shows greater variance than the other LSP-SOS methods corresponding to late understory and broadleaf SOS.

Table S1. Table showing mean phenological onset dates (mean-SOS) and trends of species-specific GP and their ID numbers (No) for the period 2001–2013. Note: HA (herbaceous annuals), HP (herbaceous perennials) and WP (woody perennials) are understory leaf unfolding dates; U (Conifers leaf unfolding); and LU (leaf unfolding) and G (greening) for broad leaf species.

ID/No.	Species	Type	Mean Sos (Doy)	Trend (Days/Year)	ID/No.	Species	Type	Mean Sos (Doy)	Trend (Days/Year)
1	*Galanthus nivalis*	HP	35.15	0.68	62	*Phyteuma spicatum*	HP	88.46	1.12
2	*Ficaria verna*	HP	48.15	0.45	63	*Galium odoratum*	HP	89.15	0.79
3	*Lamium purpureum*	HA	52.15	2.09	64	*Stachys sylvatica*	HP	89.15	0.35
4	*Leucojum vernum*	HP	56.07	0.6	65	*Ribes rubrum*	WP	89.69	1.43
5	*Aegopodium podagraria*	HP	57.61	2	66	*Stellaria nemorum*	HP	90.23	0.42
6	*Chelidonium majus*	HP	59.3	2.63	67	*Viburnum opulus*	WP	90.23	0.73
7	*Cirsium vulgare*	HA	62	2.15	68	*Scrophularia nodosa*	HP	90.3	0.22
8	*Geum urbanum*	HP	64.3	2.05	69	*Crataegus rhipidophylla*	WP	90.3	1.07
9	*Geranium robertianum*	HA	66.3	1.4	70	*Lathyrus linifolius*	HP	90.61	0.57
10	*Viola odorata*	HP	66.76	1.78	71	*Viburnum lantana*	HP	90.61	1.23
11	*Glechoma hederacea*	HP	69	1.92	72	*Deschampsia cespitosa*	HP	90.69	0.96
12	*Myosotis sylvatica*	HP	70.46	1.08	73	*Oxalis acetosella*	HP	90.76	0.82
13	*Stellaria holostea*	HP	70.84	3.03	74	*Ribes nigrum*	WP	92.23	0.71
14	*Pulmonaria officinalis*	HP	70.92	1.56	75	*Galium sylvaticum*	HP	92.84	0.48
15	*Gagea lutea*	HP	72.3	1.39	76	*Hieracium sylvaticum*	HP	93.84	0.59
16	*Alliaria petiolata*	HP	72.69	1.8	77	*Corylus avellana*	WP	94.3	0.65
17	*Polemonium caeruleum*	HP	74.23	2.09	78	*Hepatica nobilis*	HP	95.07	0.78
18	*Caltha palustris*	HP	74.92	1.08	79	*Rubus idaeus*	WP	95.15	0.8
19	*Milium effusum*	HP	75	0.69	80	*Lonicera xylosteum*	WP	95.53	0.55

20	*Symphytum tuberosum*	HP	75.1	1.63	81	*Euonymus europaeus*	WP	95.53	0.65
21	*Galium aparine*	HA	75.5	−1.09	82	*Angelica sylvestris*	HP	95.69	0.43
22	*Lunaria rediviva*	HP	75.76	2.03	83	*Epilobium angustifolium*	HP	96.69	0.71
23	*Anemone nemorosa*	HP	77.23	1.33	84	*Campanula rapunculoides*	HP	96.84	0.16
24	*Corydalis solida*	HP	77.76	1.49	85	*Dactylis polygama*	HP	97.15	0.28
25	*Urtica dioica*	HP	77.92	1.18	86	*Epilobium montanum*	HP	97.23	0.54
26	*Digitalis purpurea*	HA	78.3	1.17	87	*Rubus fruticosus*	WP	97.46	0.77
27	*Corydalis cava*	HP	78.38	1.18	88	*Tussilago farfara*	HP	98.38	0.84
28	*Anthriscus sylvestris*	HA	78.46	1.7	89	*Cornus sanguinea*	WP	98.76	1.14
29	*Euphorbia stricta*	HA	78.76	1.28	90	*Vaccinium myrtillus*	WP	99	0.24
30	*Primula elatior*	HP	78.84	1.15	91	*Polygonatum multiflorum*	HP	100.46	0.37
31	*Luzula sylvatica*	HP	79.07	1.08	92	*Mentha piperita*	HP	100.84	0.15
32	*Euphorbia amygdaloides*	HP	79.15	0.42	93	*Crataegus monogyna*	WP	101.84	0.29
33	*Lonicera caprifolium*	WP	79.53	1.07	94	*Sorbus aucuparia*	WP	102.07	0.26
34	*Galeobdolon luteum*	HP	79.53	2.19	95	*Lathyrus niger*	HP	102.69	0.32
35	*Lamium maculatum*	HP	79.76	1.36	96	*Rhamnus cathartica*	WP	104.53	0.12
36	*Aconitum napellus*	HP	80.15	1.86	97	*Aruncus dioicus*	HP	106.61	0.25
37	*Sambucus nigra*	WP	80.15	2.23	98	*Albies alba*	U	116.23	−0.12
38	*Allium ursinum*	HP	80.3	1.6	99	*Picea albies*	U	117.23	0.01
39	*Scirpus sylvaticus*	HP	80.53	0.68	100	*Pinus mugo*	U	124.23	−0.51
40	*Sambucus racemosa*	WP	80.84	0.47	101	*Pinus sylvestris*	U	125.15	−0.25
41	*Viola riviniana*	HP	80.92	0.31	102	*Prunus padus*	LU	94.69	1.42
42	*Ribes uva-crispa*	WP	80.92	1.23	103	*Betula pendula*	LU	100.53	0.71
43	*Valeriana officinalis*	HP	81.07	1.95	104	*Carpinus betulus*	LU	104.38	0.24
44	*Euphorbia epithymoides*	HP	81.23	0.84	105	*Prunus avium*	LU	104.38	0.36
45	*Rumex sanguineus*	HP	81.23	0.7	106	*Quercus robur*	LU	108.69	0.18
46	*Daphne mezereum*	WP	81.3	1.48	107	*Acer platanoides*	LU	109.3	0.26
47	*Symphytum officinale*	HP	82.76	1.42	108	*Fagus sylvatica*	LU	112.23	0.41
48	*Fragaria vesca*	HP	82.92	0.03	109	*Tilia platyphyllos*	LU	113.15	−0.19
49	*Phalaris arundinacea*	HA	83.15	0.93	110	*Sorbus torminalis*	LU	113.23	−0.26
50	*Viola tricolor*	HP	83.53	1.19	111	*Populus tremula*	LU	116	−0.07
51	*Sanicula europaea*	HP	83.92	0.53	112	*Quercus petraea*	LU	118	−0.03
52	*Geranium pyrenaicum*	HP	83.92	0.89	113	*Tilia cordata*	LU	118.3	−0.03
53	*Ribes sanguineum*	WP	84.38	1.47	114	*Fraxinus excelsior*	LU	122.61	0.38
54	*Lathyrus vernus*	HP	85	0.62	115	*Prunus padus*	G	105.76	0.08
55	*Digitalis grandiflora*	HP	85.92	0.79	116	*Larix decidua*	G	107.84	0.38
56	*Lychnis viscaria*	HP	86.23	0.69	117	*Betula pendula*	G	113.46	−0.2
57	*Geum rivale*	HP	86.53	0.75	118	*Acer platinoides*	G	115.61	−0.1
58	*Campanula persicifolia*	HP	87.23	0.53	119	*Fagus sylvatica*	G	120.84	−0.04
59	*Cardamine amara*	HP	87.38	0.72	120	*Quercus robur*	G	121.84	−0.38
60	*Poa nemoralis*	HP	88.15	0.79	121	*Quercus rubra*	G	126.384	−0.45
61	*Vinca minor*	HP	88.46	0.46	122	*Quercus petraea*	G	127.23	−0.14