Bucha T, Koren M, Sitkova Z, Pavlendova H, Snopkova Z (2023). **Trends and driving forces of spring phenology of oak and beech stands in the Western Carpathians from MODIS in 2000-2021**
iForest – Biogeosciences and Forestry – doi: 10.3832/ifor4121-016

Supplementary Material

Fig. S1 - Flowchart of the processing of MODIS satellite data and supporting data for modelling the onset of spring phenophases of oak and beech stands and their statistical evaluation.

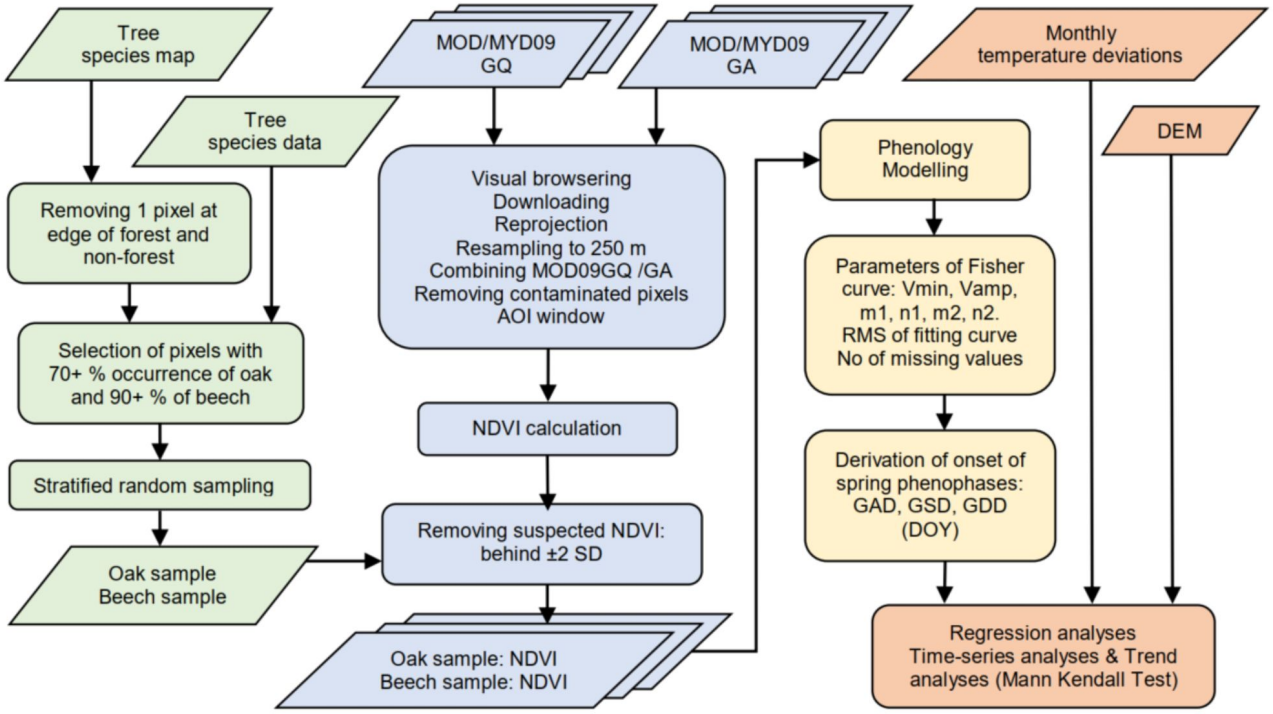


Fig. S2 - (a) Histogram of oak stands with oak representation of 70% and more; (b) Histogram of beech stands with beech representation of 90% and more. X-axis: altitude (m a.s.l.). Y-axis: number of pixels (1 pixel = 6.25 ha).

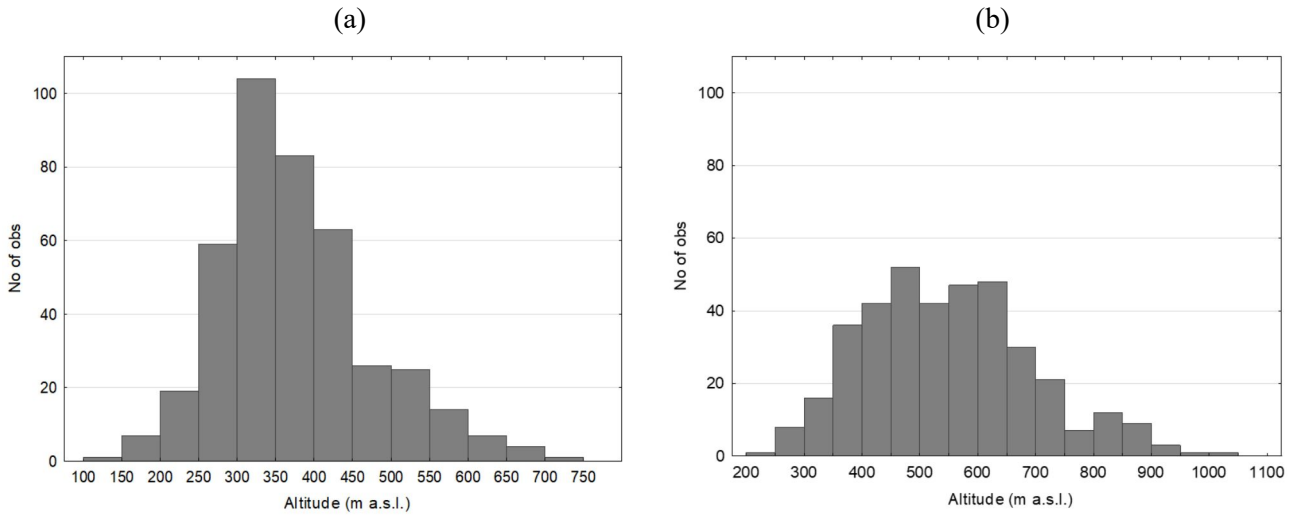


Fig. S3 - Graphical user interface of the PhenoProfile application: Calculation of the six parameters of the phenological function; 1st order derivatives (green) of the Fisher function (red). The extreme value of the first derivative in the spring phase determines the day of leaf unfolding. The x-axis shows the day of the year (DOY). The y-axis: NDVI.

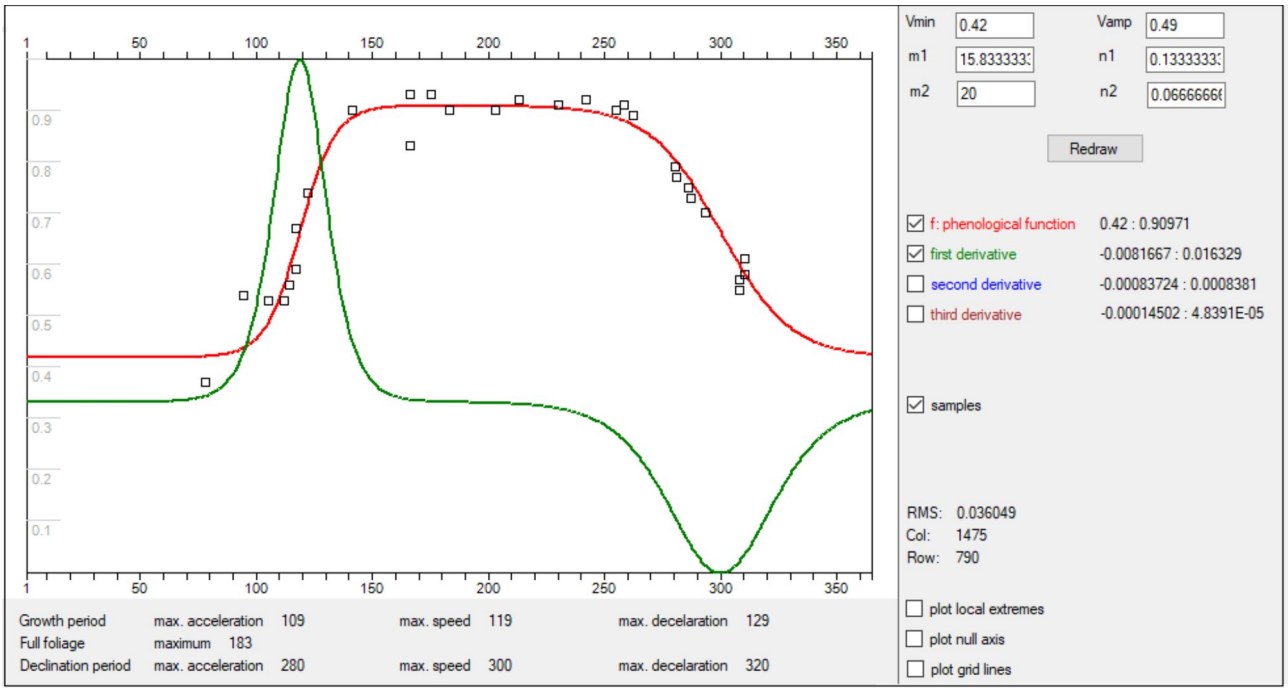


Fig. S4 - Comparison of the equality of the elevation distribution of terrestrial phenological plots of the Slovak Hydrometeorological Institute (SHMI) and samples for the derivation of satellite phenology from MODIS for oak and beech stands. Red and blue lines represent cumulative distributions of plots and samples along the elevational gradient. Two sample Kolmogorov-Smirnov test for comparison of equality of the elevation distribution of terrestrial phenological plots and MODIS samples. H0: The two samples follow the same distribution. Ha: The distributions of the two samples are different. Oak: n_1 - 22 terrestrial plots; n_2 - 413 MODIS pixels; p = 0.883 ; Beech: n_1 - 36 terrestrial plots; n_2 - 376 MODIS pixels; p = 0.236; Alpha = 0.050. As the computed p-values were greater than the significance level alpha=0.05, we cannot reject the null hypothesis H0.

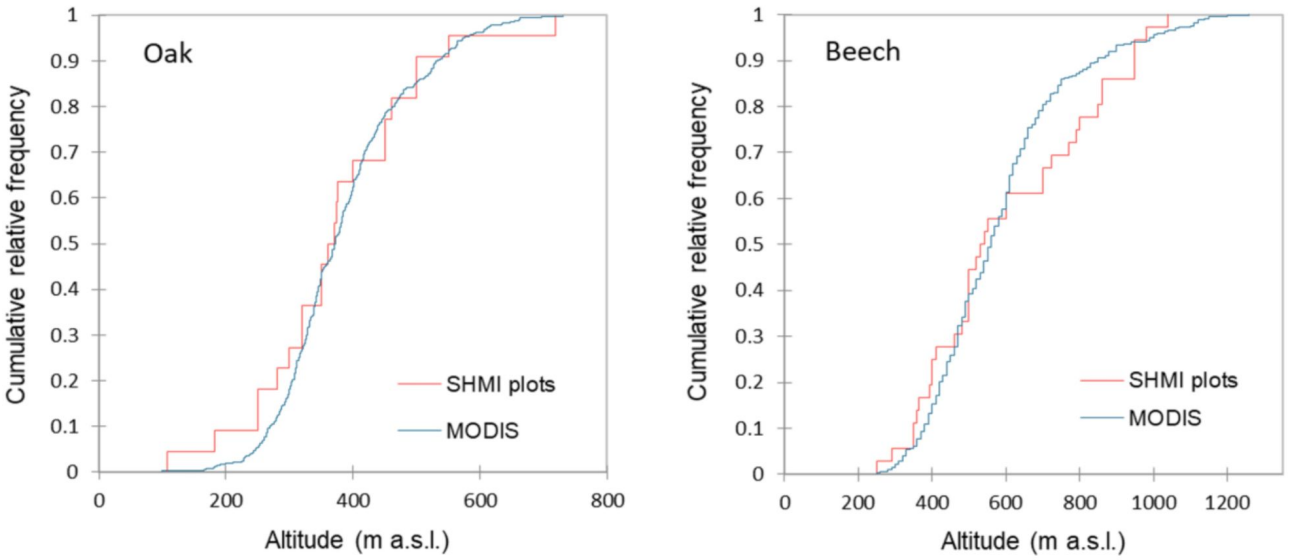
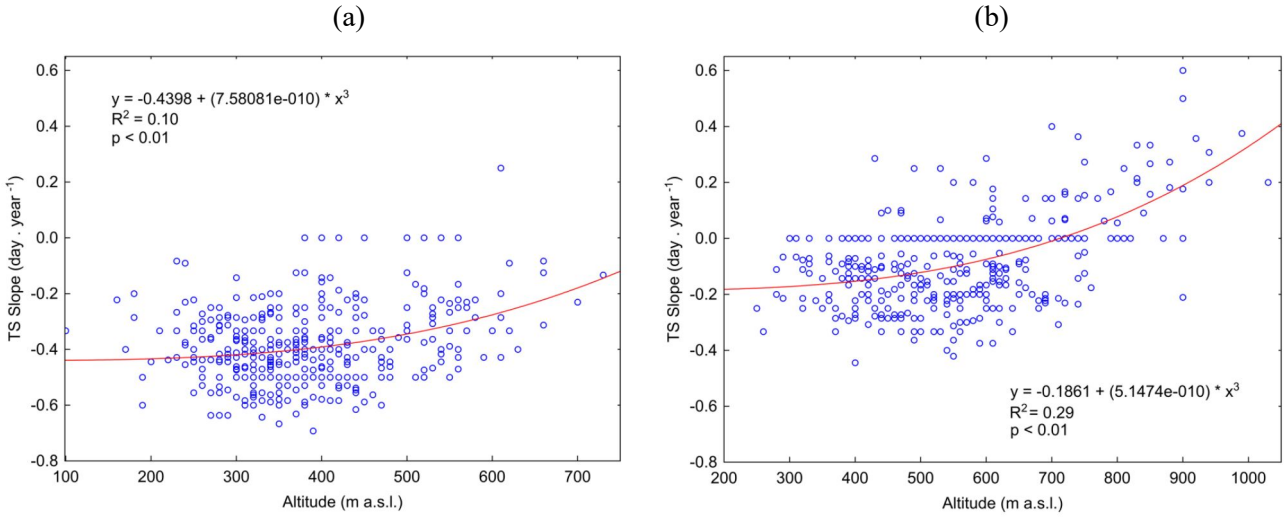


Fig. S5 - Shift in leaf unfolding onset in days per year as a function of elevation for (a) oak and (b) beech. X-axis: altitude; Y-axis: Kendall Theil-Sen slope (trend) of GSD calculated from 2000-2021 for each pixel.



Tab. S1 - Arithmetic means and medians of the day of year for the onset of Leaf unfolding (GSD metric) and derived v_{min} and v_{amp} parameters of Fisher's sigmoidal logistic function.

Year	OAK (n = 413 pixels)				BEECH (n = 376 pixels)			
	V_{min} (mean)	V_{amp} (mean)	GSD (mean)	GSD (median)	V_{min} (mean)	V_{amp} (mean)	GSD (mean)	GSD (median)
2000	0.4252	0.4688	111.36	111	0.4681	0.4356	113.56	112
2001	0.4359	0.4530	119.00	119	0.4910	0.4138	120.41	119
2002	0.4450	0.4595	116.82	119	0.5100	0.4094	117.70	117
2003	0.4205	0.4817	118.19	117	0.4801	0.4378	120.20	119
2004	0.4178	0.4743	116.52	116	0.4948	0.4182	120.03	119
2005	0.4296	0.4713	114.79	115	0.4819	0.4430	123.07	122
2006	0.4258	0.4693	115.52	115	0.4697	0.4437	119.19	118
2007	0.4343	0.4646	105.62	105	0.4952	0.4155	113.33	113
2008	0.4378	0.4592	115.27	115	0.4988	0.4130	118.72	118
2009	0.4116	0.4733	105.27	104	0.4740	0.4393	111.82	111
2010	0.4208	0.4704	115.05	115	0.4633	0.4393	120.74	119
2011	0.4173	0.4765	108.90	108	0.4718	0.4298	117.48	117
2012	0.4292	0.4433	115.47	115	0.4849	0.4154	118.81	119
2013	0.4202	0.4671	117.12	117	0.4604	0.4416	118.92	117
2014	0.4332	0.4246	96.39	96	0.4877	0.4130	107.65	105
2015	0.4458	0.4508	111.84	111	0.4816	0.4284	118.80	118
2016	0.4097	0.4631	105.39	105	0.4483	0.4417	111.38	115
2017	0.4316	0.4620	106.12	106	0.4917	0.4232	118.68	116
2018	0.4163	0.4781	106.56	107	0.4407	0.4615	109.05	108
2019	0.4283	0.4608	107.01	106	0.4907	0.4157	114.80	113
2020	0.4359	0.4618	109.71	109	0.4867	0.4124	117.80	117
2021	0.4469	0.4640	124.29	124	0.4998	0.4163	128.82	128
$Mean_{2000-2021}$	**0.43**	**0.46**	**111.92**	**111.59**	**0.48**	**0.43**	**117.32**	**116.36**
$STDev_{2000-2021}$	**0.0011**	**0.0126**	**-**	**-**	**0.0017**	**0.0144**	**-**	**-**

Tab. S2 - Monthly mean air temperatures (T in °C) in Slovakia. Source: Weather data SYNOPS/BUFR - GFS/ECMWF forecast - Meteomanz.com

Months	February	March	April
2000	-0.1	2.3	10.5
2001	-0.3	4	7.2
2002	2	4.2	7.5
2003	-4.7	2.3	6.4
2004	-1.4	2.3	8.5
2005	-4.4	0	8.3
2006	-3.8	0.3	8.9
2007	1.7	5.4	8.8
2008	0.9	3	8.2
2009	-1.7	1.9	11.5
2010	-1.7	2.5	8
2011	-2.5	3.5	9.7
2012	-6	4.5	8.7
2013	-0.9	0.5	9.1
2014	2.7	6.7	9.8
2015	-0.2	4.2	7.5
2016	3	4	9.1
2017	0.8	6	7.2
2018	-3.2	0.9	12.8
2019	1.7	5.5	9.8
2020	2.7	4.1	8.6
2021	-0.2	2.5	5.8

Tab. S3 - Monthly mean air temperature (MAT) for 1961-1990 in °C in Slovakia.

Month	MAT (°C)
February	-1.78
March	2.29
April	7.34

Tab. S4 - Calculated deviations of the monthly mean air temperatures (T in ° C) from the long-term normal 1961-1990 in Slovakia.

Year	Month			Mean		
	February	March	April	II-IV	III-IV	III-2*IV
2000	1.7	0	3.2	1.6	1.6	2.1
2001	1.5	1.7	-0.1	1	0.8	0.5
2002	3.8	1.9	0.2	2	1	0.7
2003	-2.9	0	-0.9	-1.3	-0.5	-0.6
2004	0.4	0	1.2	0.5	0.6	0.8
2005	-2.6	-2.3	1	-1.3	-0.7	-0.1
2006	-2	-2	1.6	-0.8	-0.2	0.4
2007	3.5	3.1	1.5	2.7	2.3	2
2008	2.7	0.7	0.9	1.4	0.8	0.8
2009	0.1	-0.4	4.2	1.3	1.9	2.6
2010	0.1	0.2	0.7	0.3	0.4	0.5
2011	-0.7	1.2	2.4	1	1.8	2
2012	-4.2	2.2	1.4	-0.2	1.8	1.6
2013	0.9	-1.8	1.8	0.3	0	0.6
2014	4.5	4.4	2.5	3.8	3.4	3.1
2015	1.6	1.9	0.2	1.2	1	0.7
2016	4.8	1.7	1.8	2.8	1.7	1.7

Tab. S5 - Correlation coefficients between Leaf unfolding onset (expressed by GSD metric in DOY) and the deviation of the monthly mean air temperature from the long-term normal 1961–1990 (T v °C) for oak and beech in Slovakia. Green tints represent the highest correlations.

Relations between variables: Months – GSD	**BEECH**	**OAK**	**Note**
II – GSD	-0.324	-0.409	II = February
III – GSD	-0.305	-0.496	III = March
IV – GSD	-0.784	-0.618	IV = April
AVG II-IV – GSD	-0.643	-0.718	AVG_{II-IV} = (II+III+IV) / 3
AVG III-IV – GSD	-0.816	-0.857	AVG_{III-IV} = (III+IV) / 2
AVG III-2*IV – GSD	-0.902	-0.851	$AVG_{III-2*IV}$ = (III+IV+IV) / 3