Supplementary Data

Concept of Double logistic curve:

In this study, we used the double logistic function because double logistic based curve fitting has been specifically designed for monitoring vegetation activity at high latitudes, where snow cover is present during the winter season. It was proposed by Beck et al., [1] and tested on the time series MODIS NDVI data extracted for Northern European boreal region. It estimates the NDVI and EVI of the vegetation during winter and applies a double logistic function, which is uniquely defined by six parameters that describe the yearly NDVI time series. It is already proven in previous studies that double logistic function does not overestimate the duration of the growing season and it handles outliers effectively and estimates parameters that are related to phenological events, such as the timing of spring and autumn. This makes the method most suitable for both estimating biophysical parameters and monitoring vegetation phenology at higher latitudes such as Boreal regions [1–3].

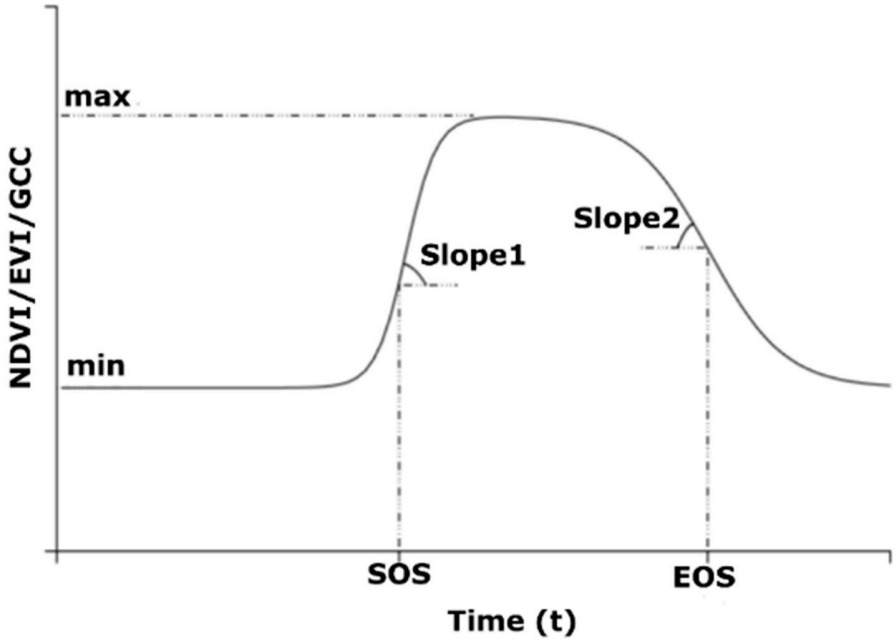


Figure S1: Example of the double logistic function (Eq. 4 in the manuscript) used to model the yearly NDVI/EVI/GCC time series. It is defined by six parameters: min and max are the minimum and maximum values measured in winter and summer, respectively, SOS and EOS are the inflection points when the curve rises and falls, and slope1 and slope2 are the rates of increase and decrease of the curve at the inflection points.

Figure S2. Example raster image of MODIS 250 spatial resolution data (base layer) and selected layover polygons (represented with black colour) from Quebec Forest inventory around PhenoCam tower site (represented with green star).

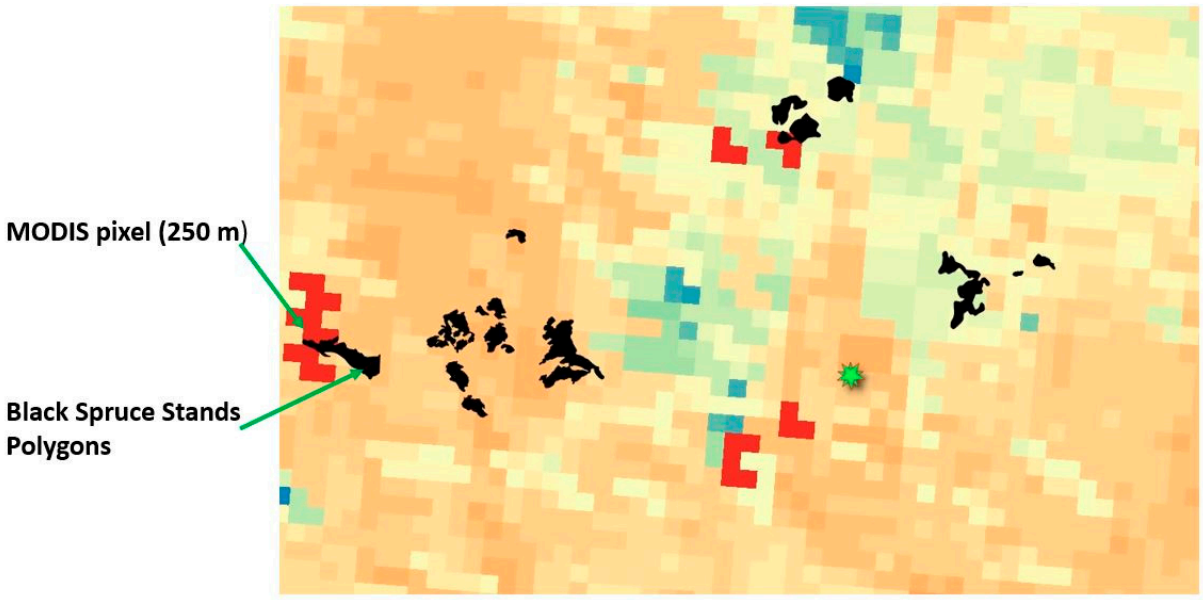


Figure S3: Statistical relationship between GCC and vegetation indices (NDVI and EVI).

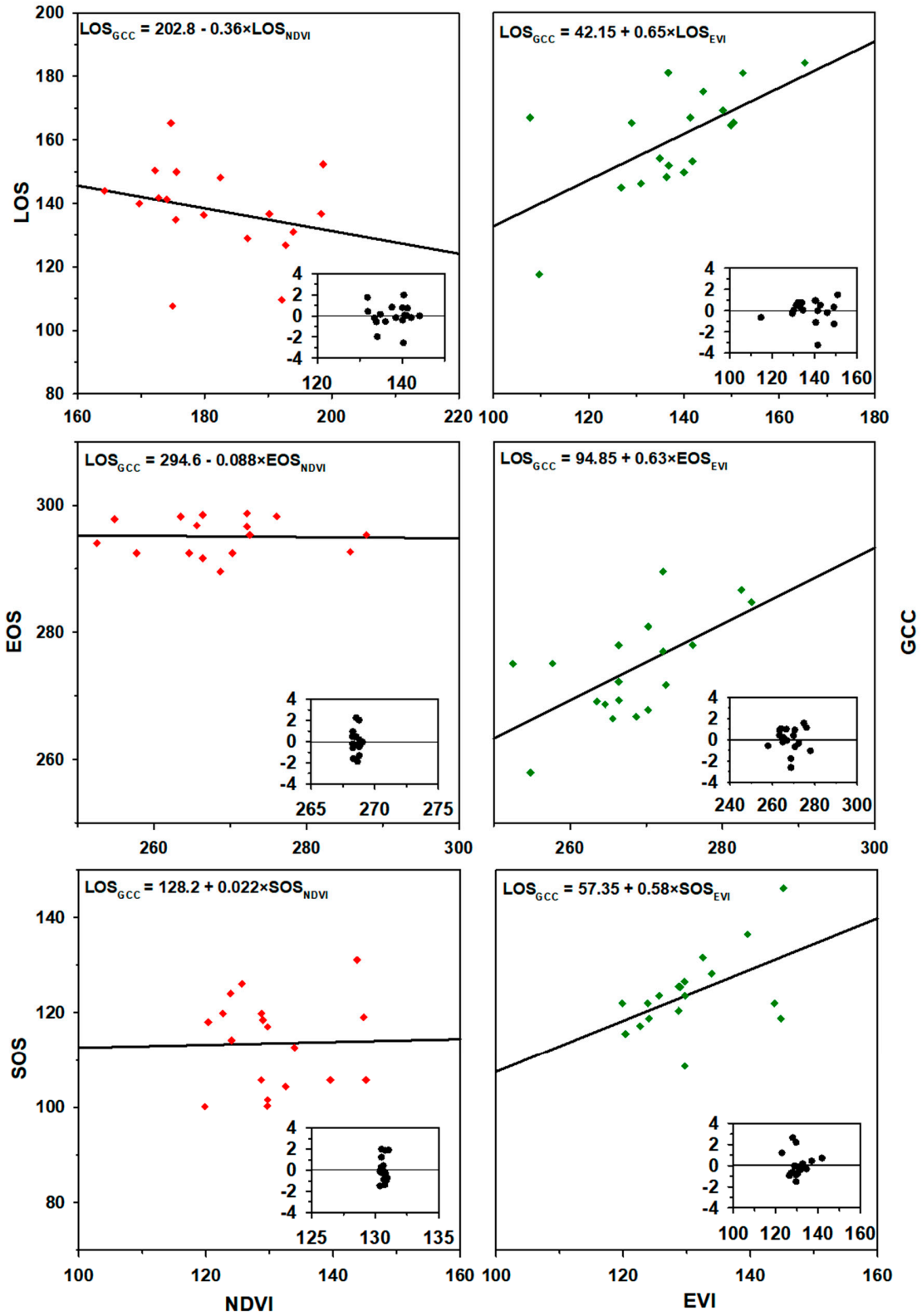


Table S1. Coefficients of the double-logistic function fitted for the GCC of black spruce during 2016, 2017, 2018 and 2019 for six sites along the latitude in Quebec.

year	site	*min*	*max*	*SOS*	*EOS*	*slope1*	*slope2*	*LOS*
2016	SIM	0.377	0.524	139.57	266.40	0.047	-0.038	126.83
2017	SIM	0.369	0.514	129.70	264.60	0.049	-0.034	134.90
2018	SIM	0.377	0.483	129.65	266.40	0.049	-0.040	136.75
2019	SIM	0.377	0.504	128.73	268.71	0.044	-0.044	139.98
2016	GAS	0.365	0.499	124.06	272.19	0.040	-0.043	148.13
2017	GAS	0.352	0.488	132.52	263.50	0.046	-0.037	130.98
2018	GAS	0.365	0.457	145.21	254.82	0.028	-0.046	109.61
2019	GAS	0.352	0.452	133.93	270.26	0.037	-0.040	136.33
2016	BER	0.335	0.416	125.68	276.08	0.028	-0.039	150.40
2017	BER	0.332	0.416	122.65	272.57	0.038	-0.030	149.92
2018	BER	0.328	0.391	120.38	285.73	0.038	-0.036	165.35
2019	BER	0.336	0.380	123.85	265.61	0.049	-0.038	141.76
2017	MIS	0.377	0.473	129.70	266.40	0.049	-0.038	136.70
2018	MIS	0.365	0.454	119.83	272.19	0.054	-0.052	152.36
2019	MIS	0.365	0.452	128.70	257.71	0.030	-0.036	129.01
2016	DAN	0.375	0.463	128.95	270.28	0.064	-0.050	141.33
2016	MIR	0.352	0.535	143.80	287.83	0.053	-0.044	144.03
2017	MIR	0.373	0.519	144.82	252.52	0.029	-0.037	107.70

Table S2. Coefficients of the double-logistic function fitted for the NDVI of black spruce during 2016, 2017, 2018 and 2019 for six sites along the latitude in Quebec.

year	site	*min*	*max*	*SOS*	*EOS*	*slope1*	*slope2*	*LOS*
2016	SIM	0.256	0.904	105.73	298.47	0.049	-0.057	192.74
2017	SIM	0.282	0.924	117.01	292.46	0.035	-0.033	175.45
2018	SIM	0.265	0.983	100.24	298.56	0.025	-0.031	198.32
2019	SIM	0.270	0.905	119.83	289.56	0.035	-0.039	169.73
2016	GAS	0.125	0.950	114.19	296.67	0.049	-0.046	182.48
2017	GAS	0.128	0.927	104.32	298.25	0.040	-0.048	193.93
2018	GAS	0.107	0.925	105.73	297.85	0.039	-0.045	192.12
2019	GAS	0.105	0.938	112.6	292.46	0.036	-0.045	179.86
2016	BER	0.177	0.772	126.07	298.25	0.043	-0.041	172.18
2017	BER	0.171	0.748	119.83	295.35	0.056	-0.052	175.52
2018	BER	0.137	0.752	118.01	292.68	0.055	-0.055	174.67
2019	BER	0.174	0.763	124.06	296.83	0.055	-0.053	172.77
2017	MIS	0.219	0.917	101.51	291.66	0.031	-0.041	190.15
2018	MIS	0.176	0.910	100.1	298.73	0.031	-0.042	198.63
2019	MIS	0.122	0.858	105.73	292.46	0.033	-0.048	186.73
2016	DAN	0.083	0.739	118.42	292.46	0.045	-0.034	174.04
2016	MIR	0.155	0.927	131.11	295.35	0.037	-0.040	164.24
2017	MIR	0.148	0.840	119.08	294.034	0.041	-0.049	174.95

Table S3. Coefficients of the double-logistic function fitted for the EVI of black spruce during 2016, 2017, 2018 and 2019 for six sites along the latitude in Quebec.

year	site	*min*	*max*	*SOS*	*EOS*	*slope1*	*slope2*	*LOS*
2016	SIM	0.207	0.864	138.16	272.19	0.022	-0.021	134.03
2017	SIM	0.211	0.853	126.88	268.63	0.022	-0.019	141.75
2018	SIM	0.176	0.850	129.45	269.29	0.026	-0.019	139.84
2019	SIM	0.187	0.813	128.59	266.68	0.021	-0.019	138.09
2016	GAS	0.084	0.813	122.65	276.98	0.035	-0.028	154.33
2017	GAS	0.086	0.769	133.93	269.08	0.025	-0.030	135.15
2018	GAS	0.086	0.740	146.62	257.92	0.027	-0.024	111.30
2019	GAS	0.078	0.444	130.91	267.77	0.041	-0.038	136.86
2016	BER	0.139	0.491	126.88	277.98	0.032	-0.032	151.10
2017	BER	0.149	0.461	121.24	271.68	0.045	-0.040	150.44
2018	BER	0.164	0.667	119.83	286.67	0.026	-0.028	166.84
2019	BER	0.127	0.721	125.47	266.4	0.028	-0.021	140.93
2017	MIS	0.111	0.752	113.79	277.98	0.013	-0.021	164.19
2018	MIS	0.114	0.519	125.47	289.56	0.013	-0.024	164.09
2019	MIS	0.075	0.512	124.06	275.08	0.015	-0.024	151.02
2016	DAN	0.145	0.589	128.47	280.88	0.024	-0.025	152.41
2016	MIR	0.139	0.515	125.47	284.75	0.038	-0.039	159.28
2017	MIR	0.054	0.400	122.65	275.08	0.039	-0.037	152.43

References used in supplementary data

1. Beck, P.S.A.; Atzberger, C.; Høgda, K.A.; Johansen, B.; Skidmore, A.K. Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI. *Remote Sens. Environ.* **2006**, *100*, 321–334, doi:10.1016/j.rse.2005.10.021.

2. Antonucci, S.; Rossi, S.; Deslauriers, A.; Morin, H.; Lombardi, F.; Marchetti, M.; Tognetti, R. Large-scale estimation of xylem phenology in black spruce through remote sensing. *Agric. For. Meteorol.* **2017**, *233*, 92–100, doi:10.1016/j.agrformet.2016.11.011.

3. Khare, S.; Drolet, G.; Sylvain, J.D.; Paré, M.C.; Rossi, S. Assessment of spatio-temporal patterns of black spruce bud phenology across Quebec based on MODIS-NDVI time series and field observations. *Remote Sens.* **2019**, *11*, 2745, doi:10.3390/rs11232745.