

# The North Atlantic Oscillation system and plant phenology

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**Abstract** The onset of flowering in 78 wild and domesticated terrestrial plant species recorded in South Moravia (Czech Republic) from 1965 to 2014 was correlated with the North Atlantic Oscillation (NAO) index of the preceding winter. Flowering occurred significantly earlier following positive winter NAO phases (causing spring to be warmer than normal in Central Europe) in nearly all early-flowering (March, April) species; high Pearson correlation values were recorded in, e.g., goat willow, spring snowflake, golden bell, cornelian cherry, sweet violet, cherry plum, grape hyacinth, apricot, blackthorn, common dandelion, cherry, southern magnolia, common apple, cuckoo flower, European bird cherry, and cherry laurel. In contrast, the timing of later-flowering plant species (May to July) did not correlate significantly with the winter NAO index. It was found that local temperature is obviously a proximate factor of plant phenology, while the winter NAO is the ultimate factor, affecting temperature and other meteorological phenomena in Central Europe during spring season.

**Keywords** NAO · Atmospheric circulation · Weather · Temperature · Flowering timing · Czech Republic

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## Introduction

The North Atlantic Oscillation system (NAO) of atmospheric circulation is a major determinant of weather and climate fluctuation in Europe and eastern North America (Wallace and Gutzler 1981; Barnston and Livezey 1987; Hurrell 1995). The winter NAO index is a simple approximate descriptor of weather over most of Europe in the following spring and summer. It also affects phenological phases of different biota. While a number of papers have reported the relationship between the NAO and animal (bird, fish, etc.) phenology, the effect of the NAO on the timing of flowering in plants has been studied relatively less often, and the studies generally involved only a limited number of plant species in a few European countries (Post and Stenseth 1999; Scheifinger et al. 2002; Menzel 2003; Aasa et al. 2004; Cook et al. 2005; Gormsen et al. 2005; Ahas and Aasa 2006; Menzel et al. 2008; Nordli et al. 2008; Kalvane et al. 2009), with some exceptions (Menzel et al. 2005).

However, the effect of the NAO on biota might differ regionally within Europe. The aim of the present study was to evaluate whether the NAO also affected the flowering of plants in Central Europe. In this study, a longitudinal record (spanning up to 50 years) on the onset of flowering in a large number of plant species growing in southern Moravia (Czech Republic) was correlated with the winter NAO index. In addition, the effect of local meteorological variables (temperature, precipitation, snow cover, relative humidity of the air) on the flowering was also evaluated.

**Table 1** Mean flowering date of 78 plant species (*Mean*, Julian days) in *n* recorded years, and correlation (*r*, Pearson's product-moment coefficient) with winter NAO index

Plant species	<i>Mean</i>	<i>n</i>	<i>Min</i>	<i>Max</i>	<i>SD</i>	<i>r</i>
Goat willow, <i>Salix caprea</i>	66.2	28	42	97	14.835	<b>-0.590</b>
Spring snowflake, <i>Leucojum vernum</i>	76.3	18	58	102	10.429	<b>-0.558</b>
Two-leaf squill, <i>Scilla bifolia</i>	85.6	26	69	106	8.850	<b>-0.422</b>
Golden bell, <i>Forsythia viridissima</i>	87.4	47	64	110	11.643	<b>-0.647</b>
Cornelian cherry, <i>Cornus mas</i>	87.5	40	63	114	10.164	<b>-0.517</b>
Lesser celandine, <i>Ranunculus ficaria</i>	87.9	45	49	111	12.852	<b>-0.332</b>
Coltsfoot, <i>Tussilago farfara</i>	88.6	40	67	109	9.677	<b>-0.325</b>
Yellow star-of-Bethlehem, <i>Gagea lutea</i>	90.3	38	69	112	10.508	<b>-0.393</b>
Sweet violet, <i>Viola odorata</i>	91.0	48	75	117	10.206	<b>-0.531</b>
Common lungwort, <i>Pulmonaria officinalis</i>	91.4	46	64	119	11.826	<b>-0.399</b>
Cherry plum, <i>Prunus cerasifera</i>	92.2	26	71	115	10.586	<b>-0.548</b>
Grape hyacinth, <i>Muscari racemosum</i>	92.4	20	68	114	11.169	<b>-0.526</b>
Daffodil, <i>Narcissus pseudonarcissus</i>	92.9	29	78	119	9.969	<b>-0.430</b>
Corydalis, <i>Corydalis cava</i>	94.1	40	79	110	8.123	<b>-0.396</b>
Yellow anemone, <i>Anemone ranunculoides</i>	95.2	46	75	128	10.236	<b>-0.412</b>
Apricot tree, <i>Prunus armeniaca</i>	95.9	45	74	114	10.081	<b>-0.535</b>
Silver birch, <i>Betula pendula</i> – leaf unfolding	97.4	29	71	112	8.049	<b>-0.472</b>
Cowslip primrose, <i>Primula veris</i>	98.0	26	78	119	10.279	<b>-0.388</b>
Norway maple, <i>Acer platanoides</i>	100.1	38	82	116	8.462	<b>-0.460</b>
Blackthorn, <i>Prunus spinosa</i>	101.5	47	80	129	10.015	<b>-0.535</b>
Common dandelion, <i>Taraxacum officinale</i>	102.1	45	84	126	9.693	<b>-0.543</b>
Cherry, <i>Prunus cerasus</i>	105.3	40	85	129	9.522	<b>-0.523</b>
Southern magnolia, <i>Magnolia grandiflora</i>	105.4	45	80	129	10.052	<b>-0.527</b>
Peach tree, <i>Prunus persica</i>	105.8	37	87	119	8.142	<b>-0.457</b>
Spotted henbit, <i>Lamium maculatum</i>	106.6	32	91	128	9.724	<b>-0.479</b>
Jap. flowering cherry (sakura), <i>Prunus serrulata</i>	108.5	41	87	136	10.186	<b>-0.398</b>
Yellow marsh marigold, <i>Caltha palustris</i>	110.1	27	91	120	7.068	-0.240
Spring pea, <i>Lathyrus vernus</i>	110.4	26	98	134	8.228	-0.154
Common pear, <i>Pyrus communis</i>	111.2	21	97	124	7.082	-0.357
Common apple, <i>Malus pumila</i>	111.6	31	96	125	8.545	<b>-0.548</b>
Cypress spurge, <i>Euphorbia cyparissias</i>	112.2	32	96	130	8.402	-0.230
Cuckoo flower, <i>Cardamine pratensis</i>	114.5	30	98	142	9.688	<b>-0.540</b>
Garlic mustard, <i>Alliaria petiolata</i>	115.0	36	96	127	7.674	<b>-0.379</b>
Common sedge, <i>Carex nigra</i>	115.3	21	95	140	9.249	<b>-0.472</b>
White deadnettle, <i>Lamium album</i>	115.6	29	94	139	10.210	<b>-0.482</b>
Celandine, <i>Chelidonium majus</i>	115.8	31	94	132	9.096	-0.297
Wayfaring tree, <i>Viburnum lantana</i>	116.2	30	97	130	8.224	<b>-0.438</b>
Common bugle, <i>Ajuga reptans</i>	116.8	30	98	137	9.222	-0.202
Common lilac, <i>Syringa vulgaris</i>	117.6	44	98	131	8.086	<b>-0.415</b>
European bird cherry, <i>Prunus padus</i>	118.0	22	102	130	6.371	<b>-0.532</b>
Cherry laurel, <i>Prunus laurocerasus</i>	120.0	15	102	132	7.554	<b>-0.568</b>
Common snowberry, <i>Symphoricarpos albus</i>	121.0	28	70	136	12.307	-0.181
Horse chestnut, <i>Aesculus hippocastanum</i>	121.4	46	105	135	6.701	<b>-0.329</b>
Woodland strawberry, <i>Fragaria vesca</i>	122.9	23	109	135	5.980	-0.169
Whitetop, <i>Lepidium draba</i>	123.2	30	110	134	6.152	-0.310
Shrubby cinquefoil, <i>Dasiphora fruticosa</i>	126.4	16	106	155	13.370	-0.191
Showy buttercup, <i>Ranunculus acris</i>	126.5	28	107	145	8.038	-0.047
Ramsons, <i>Allium ursinum</i>	126.6	18	106	163	14.135	-0.241

**Table 1** (continued)

Plant species	Mean	n	Min	Max	SD	r
Crambe, <i>Crambe tataria</i>	127.4	26	109	156	8.025	−0.152
French tamarisk, <i>Tamarix gallica</i>	127.8	37	115	148	7.782	−0.187
Common comfrey, <i>Symphytum officinale</i>	127.9	38	109	148	9.353	−0.193
European mountain ash, <i>Sorbus aucuparia</i>	128.5	15	118	137	5.214	−0.434
Midland hawthorn, <i>Crataegus laevigata</i>	128.9	23	115	144	7.471	−0.044
Field chickweed, <i>Cerastium arvense</i>	129.5	15	118	148	8.709	−0.248
Bladder campion, <i>Silene latifolia</i> ssp. <i>alba</i>	130.6	25	111	146	8.333	−0.143
Red clover, <i>Trifolium pratense</i>	131.7	15	119	144	6.071	−0.029
Ox-eye daisy, <i>Leucanthemum vulgare</i>	132.3	22	119	146	5.832	−0.159
Ragged Robin, <i>Silene flos-cuculi</i>	132.3	25	121	146	5.822	−0.128
Introduced sage, <i>Salvia pratensis</i>	133.4	35	119	151	7.571	−0.039
Birthwort, <i>Aristolochia clematitis</i>	133.5	25	123	153	7.094	−0.151
Yellow mignonette, <i>Reseda lutea</i>	133.9	17	121	145	7.235	0.217
Purple mullein, <i>Verbascum phoeniceum</i>	134.7	32	117	156	9.586	−0.048
Europ. Black elderberry, <i>Sambucus nigra</i>	138.3	32	122	161	9.019	−0.190
Red dogwood, <i>Cornus sanguinea</i>	139.1	18	113	160	9.427	0.200
Corn poppy, <i>Papaver rhoeas</i>	139.5	21	122	155	7.372	−0.182
Black locust tree, <i>Robinia pseudoacacia</i>	140.7	39	127	161	8.023	−0.255
Yellow flag, <i>Iris pseudacorus</i>	140.9	33	129	168	8.114	−0.175
Cock's-foot, <i>Dactylis glomerata</i>	143.2	19	117	160	9.545	−0.208
Dog rose, <i>Rosa canina</i>	143.7	17	127	164	10.168	−0.322
Oleaster, <i>Eleagnus angustifolia</i>	149.5	28	137	167	7.336	−0.254
Common privet, <i>Ligustrum vulgare</i>	153.1	25	125	177	12.343	0.231
Littleleaf linden, <i>Tilia cordata</i>	158.7	26	144	175	7.750	0.047
Goatsbeard, <i>Tragopogon orientalis</i>	159.3	18	140	187	11.943	0.250
Spanish chestnut, <i>Castanea sativa</i>	162.0	15	154	176	5.904	−0.110
Common viper's bugloss, <i>Echium vulgare</i>	165.9	15	152	189	10.275	0.151
Yucca, <i>Yucca flaccida</i>	171.8	18	162	189	9.100	−0.220
Southern catalpa, <i>Catalpa bignonioides</i>	174.2	28	157	192	9.408	0.064
Pagoda tree, <i>Styphnolobium japonicum</i>	197.3	20	169	223	13.150	0.107

Significant ( $P < 0.05$ ) correlation values are printed in bold. Species are arranged in order of mean date

SD standard deviation

## Materials and methods

### Study area

Observations were made in the district of Breclav (48° 40′–49° 05′ N, 16° 30′–17° 00′ E; ~150–200 m above sea level), southern Moravia (Czech Republic).

### Phenological records

Long-term records of phenological events of particular plant species were made by the author during the period 1965–2014. Excluding plant species with less than 15 annual records resulted in 78 wild and domesticated terrestrial plant species retained for analysis. Plants were checked for flowering every

3–4 days from March to July. The beginning of flowering was defined as the calendar date when approximately 20 % of flowers of a particular plant population or a tree/shrub were already open. In one species (silver birch), leafing (~20 % leaf unfolding) was used as the phenological event.

### North Atlantic Oscillation data

Winter (December–March) NAO indices for the study years were obtained from [https://climatedataguide.ucar.edu/sites/default/files/climate\\_index\\_files/nao\\_station\\_djfm\\_0.txt](https://climatedataguide.ucar.edu/sites/default/files/climate_index_files/nao_station_djfm_0.txt) (Hurrell 1995). This index is station-based on normalized sea level pressure differences between Ponta Delgada (Azores) and Stykkisholmur (Iceland). A positive NAO index means that the atmospheric pressure over the subtropical part of the

**Table 2** Mean Pearson correlation coefficients ( $r$ ) between the winter NAO index and onset of flowering of 78 plant species

	No. of plant species	No. (%) of significant correlations	Mean overall $r$ value
March	8	8 (100 %)	-0.473
April	33	27 (82 %)	-0.437
May	29	1 (3 %)	-0.158
June + July	8	0 (0 %)	+0.065

Species are grouped according to the month of their mean flowering date

North Atlantic is higher than normal while that over the northern sector of the North Atlantic is lower than normal; this increased pressure difference between the two sectors results in more and stronger storms crossing the Atlantic Ocean and, in turn, also causes warm and wet weather in northern and central Europe (Hurrell 1995). A negative NAO index reflects the opposite pattern of height and pressure anomalies over these sectors; this reduced pressure gradient results in fewer and weaker storms crossing the Atlantic Ocean and brings cold air to northern and central Europe and moist and often cold air into the Mediterranean.

### Local meteorological data

Daily meteorological data, obtained from the meteorological station Lednice (situated in the study area 48.79 N, 16.80 E; 173 m a.s.l.) for the years 1965–2014, were supplied by the Czech Hydrometeorological Institute in Brno: average (TAVG), maximum (TMAX), and minimum (TMIN) temperature of the air, precipitation (mm, PREC), snow cover (cm, SNOW) at 07 h, and relative humidity of the air (% , RH). Monthly and annual averages (TAVG, TMAX, TMIN, SNOW, RH) or sums (PREC) were calculated and compared with seasonal NAO data and phenological events in individual plant species.

### Statistical analysis

Calendar dates of phenological events were transformed into Julian days. Pearson correlations were used to examine the

linear relationships between the winter NAO index or meteorological data and phenological events of each plant species. The data did not deviate significantly from a normal distribution, and there was no significant autocorrelation at lag 1 within the winter NAO index (results not shown).

### Results

A significant ( $P<0.05$ ) correlation between flowering and winter NAO index was found in 36 of the 78 species tested (Table 1). All these species were negatively correlated with the winter NAO index, i.e., flowering started earlier following the higher NAO index values. Nearly all early spring flowering plant species had significant correlations with the winter NAO index (Table 2), and markedly high  $r$  values,  $|r|>0.5$ , were recorded in goat willow, spring snowflake, golden bell, cornelian cherry, sweet violet, cherry plum, grape hyacinth, apricot, blackthorn, common dandelion, cherry, southern magnolia, common apple, cuckoo flower, European bird cherry, and cherry laurel. This indicates that more than 25 % of the variability in the start of flowering of these plant species is attributable to the NAO index. In contrast, all of the later-flowering plant species (those flowering in May, June, and July), except for horse chestnut, which is however the earliest of later-flowering species, did not correlate significantly with the winter NAO index.

For the study area, a significant long-term correlation was found between the winter NAO index and local air temperature ( $r=+0.500$ ), precipitation ( $r=-0.341$ ), snow cover ( $r=-0.691$ ), and relative humidity of the air ( $r=-0.443$ ) in the period from 1965 to 2014 (50 years, Table 3). The results for TMAX and TMIN were similar to those for TAVG and are not given in Table 3.

Table 4 shows Pearson correlation between flowering events in plants and the winter NAO or monthly meteorological data (TAVG, PREC, SNOW, RH) recorded in the study area from 1965 to 2014. In all plant species with significant correlation of flowering event with the winter NAO, a significant correlation was also detected with the air temperature in January, February, or March—the only exception being cherry laurel. Sometimes, the correlation with temperature was

**Table 3** Correlation between the winter NAO index and meteorological data in Lednice (South Moravia), 1965–2014 (50 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Year
TAVG	<b>+0.540</b>	<b>+0.326</b>	<b>+0.465</b>	+0.091	+0.121	+0.023	+0.194	<b>+0.500</b>
PREC	<b>-0.465</b>	<b>-0.302</b>	-0.118	-0.086	<b>-0.306</b>	-0.197	-0.123	<b>-0.341</b>
SNOW	<b>-0.584</b>	<b>-0.522</b>	<b>-0.370</b>	<b>-0.387</b>	n/a	n/a	n/a	<b>-0.691</b>
RH	-0.218	<b>-0.304</b>	<b>-0.370</b>	-0.087	<b>-0.341</b>	-0.276	<b>-0.353</b>	<b>-0.443</b>

Significant ( $P<0.05$ ) correlation values are printed in bold

TAVG average temperature, PREC precipitation, SNOW snow cover, RH relative humidity of the air

**Table 4** Pearson correlation coefficients between flowering events in plants and winter NAO index or monthly regional meteorological data—air temperature (TAVG), precipitation, snow cover, and relative humidity of the air

	NAO DJFM	TAVG Jan	TAVG Feb	TAVG Mar	TAVG Apr	TAVG May	PREC Jan	PREC Feb	PREC Mar	PREC Apr	PREC May	SNOW Jan	SNOW Feb	SNOW Mar	SNOW Apr	SNOW May	RH Jan	RH Feb	RH Mar	RH Apr	RH May
Goat willow	-0.590	-0.673	-0.533	-0.529	-0.007	-0.186	+0.388	+0.150	+0.081	+0.250	+0.405	+0.500	+0.560	+0.507	+0.287	-0.085	+0.146	+0.358	-0.002	-0.002	+0.216
Spring snowflake	-0.558	-0.317	-0.497	-0.723	-0.158	-0.295	+0.306	+0.289	-0.053	+0.136	+0.446	+0.282	+0.491	+0.303	+0.000	+0.024	+0.225	+0.317	+0.143	+0.143	+0.387
Two-leaf squill	-0.422	-0.596	-0.607	-0.705	+0.106	-0.142	+0.126	+0.187	-0.022	-0.152	+0.134	+0.404	+0.610	+0.369	+0.343	-0.034	+0.188	+0.469	-0.084	-0.084	+0.301
Golden bell	-0.647	-0.566	-0.634	-0.776	-0.140	-0.241	+0.403	+0.360	+0.014	-0.025	+0.264	+0.475	+0.592	+0.531	+0.360	+0.037	+0.324	+0.510	-0.013	-0.013	+0.330
Comelian cherry	-0.517	-0.461	-0.623	-0.715	-0.127	-0.193	+0.358	+0.251	+0.033	-0.082	+0.336	+0.318	+0.501	+0.465	+0.432	-0.090	+0.157	+0.443	-0.129	-0.129	+0.330
Lesser celandine	-0.332	-0.568	-0.426	-0.512	-0.244	-0.286	+0.110	+0.033	-0.096	+0.046	+0.150	+0.355	+0.258	+0.181	+0.152	+0.061	+0.284	+0.323	+0.222	+0.222	+0.283
Coltsfoot	-0.325	-0.203	-0.322	-0.514	+0.153	+0.082	+0.408	+0.301	+0.117	-0.001	-0.082	+0.107	+0.277	+0.209	-0.004	-0.120	+0.224	+0.099	-0.087	-0.087	+0.047
Yellow star-of-Bethlehem	-0.393	-0.407	-0.561	-0.669	-0.006	-0.052	+0.272	+0.179	-0.029	+0.055	+0.172	+0.345	+0.488	+0.301	+0.337	-0.067	+0.183	+0.258	-0.044	-0.044	+0.209
Sweet violet	-0.531	-0.480	-0.452	-0.783	-0.252	-0.187	+0.312	+0.320	-0.038	+0.039	+0.104	+0.393	+0.372	+0.350	+0.202	+0.063	+0.393	+0.428	+0.144	+0.144	+0.220
Common lungwort	-0.399	-0.364	-0.386	-0.480	-0.118	-0.073	+0.382	+0.287	-0.123	+0.069	+0.099	+0.202	+0.444	+0.332	+0.271	+0.112	+0.339	+0.243	-0.064	-0.064	+0.165
Cherry plum	-0.548	-0.668	-0.642	-0.743	-0.037	-0.101	+0.317	+0.325	+0.129	+0.042	+0.235	+0.470	+0.687	+0.617	+0.481	-0.027	+0.084	+0.460	-0.171	-0.171	+0.167
Grape hyacinth	-0.526	-0.551	-0.518	-0.541	+0.069	-0.117	+0.255	+0.005	-0.126	-0.476	+0.216	+0.504	+0.372	+0.298	+0.224	-0.202	+0.169	+0.031	-0.459	-0.459	+0.121
Daffodil	-0.430	-0.627	-0.422	-0.780	-0.018	-0.302	+0.243	+0.253	+0.045	+0.139	+0.210	+0.595	+0.527	+0.488	-0.057	-0.111	+0.390	+0.261	+0.017	+0.017	+0.104
Corydalis	-0.396	-0.504	-0.475	-0.714	-0.062	-0.086	+0.264	+0.294	+0.032	-0.078	+0.186	+0.408	+0.480	+0.499	+0.305	-0.160	+0.092	+0.375	-0.160	-0.160	+0.071
Yellow anemone	-0.412	-0.471	-0.502	-0.690	-0.215	-0.282	+0.097	+0.299	-0.071	+0.042	+0.036	+0.352	+0.433	+0.614	+0.337	-0.075	+0.280	+0.410	+0.129	+0.129	+0.171
Apricot tree	-0.535	-0.595	-0.625	-0.743	-0.230	-0.162	+0.271	+0.285	+0.094	-0.006	+0.141	+0.476	+0.459	+0.504	+0.340	-0.093	+0.135	+0.467	+0.001	+0.001	+0.140
Silver birch – leaf unfolding	-0.472	-0.483	-0.167	-0.317	+0.102	-0.050	+0.212	+0.179	+0.170	+0.416	+0.159	+0.402	+0.401	+0.317	-0.157	-0.299	-0.095	+0.030	+0.140	+0.140	+0.019
Cowslip primrose	-0.388	-0.514	-0.597	-0.860	+0.027	-0.028	+0.404	+0.212	-0.007	-0.142	+0.161	+0.438	+0.635	+0.646	+0.441	-0.237	+0.048	+0.417	-0.334	-0.334	+0.109
Norway maple	-0.460	-0.561	-0.598	-0.748	-0.298	-0.313	+0.236	+0.159	-0.110	+0.037	+0.264	+0.384	+0.483	+0.461	+0.359	-0.067	+0.234	+0.393	-0.074	-0.074	+0.221
Blackthorn	-0.535	-0.554	-0.625	-0.756	-0.304	-0.285	+0.081	+0.043	+0.043	+0.024	+0.375	+0.419	+0.457	+0.481	+0.288	+0.008	+0.235	+0.487	+0.052	+0.052	+0.256
Common dandelion	-0.543	-0.507	-0.639	-0.743	-0.162	-0.204	+0.117	+0.059	-0.009	-0.083	+0.341	+0.424	+0.640	+0.478	+0.331	-0.133	+0.193	+0.507	-0.066	-0.066	+0.215
Cherry	-0.523	-0.469	-0.519	-0.776	-0.185	-0.042	+0.046	+0.042	+0.215	-0.106	+0.258	+0.298	+0.354	+0.446	+0.290	-0.116	+0.230	+0.503	-0.153	-0.153	+0.129
Southern magnolia	-0.527	-0.386	-0.475	-0.731	-0.371	-0.231	+0.161	+0.130	+0.041	-0.028	+0.142	+0.352	+0.325	+0.407	+0.303	+0.083	+0.289	+0.538	+0.061	+0.061	+0.149
Peach tree	-0.457	-0.405	-0.606	-0.684	-0.164	+0.0316	+0.172	+0.054	-0.020	-0.151	+0.066	+0.445	+0.439	+0.354	+0.296	-0.083	+0.084	+0.264	-0.199	-0.199	-0.039
Spotted henbit	-0.479	-0.608	-0.405	-0.760	-0.232	-0.344	+0.162	+0.131	+0.061	+0.083	+0.062	+0.486	+0.387	+0.283	+0.331	-0.084	+0.235	+0.272	+0.178	+0.178	+0.166
Jap. flowering cherry (sakura)	-0.398	-0.244	-0.299	-0.539	+0.009	-0.193	-0.029	-0.028	-0.050	+0.233	+0.125	+0.087	+0.354	+0.428	+0.206	+0.070	+0.148	+0.238	+0.149	+0.149	+0.237
Yellow marsh marigold	-0.240	+0.061	-0.259	-0.403	+0.017	+0.023	-0.244	+0.327	+0.215	-0.263	-0.123	-0.066	+0.185	+0.264	-0.119	-0.080	-0.182	+0.059	-0.185	-0.185	-0.240
Spring pea	-0.154	-0.057	-0.258	-0.401	-0.277	-0.495	-0.034	+0.161	+0.006	-0.053	+0.249	-0.019	+0.328	+0.028	+0.000	-0.052	+0.332	+0.081	+0.123	+0.123	+0.455
Common pear	-0.357	-0.268	-0.217	-0.505	-0.265	-0.104	-0.102	-0.031	+0.239	-0.319	+0.226	+0.272	+0.100	-0.115	+0.414	+0.233	+0.362	+0.621	+0.125	+0.125	+0.154
Common apple	-0.548	-0.281	-0.531	-0.533	-0.361	+0.012	+0.021	+0.145	+0.061	-0.029	+0.143	+0.199	+0.427	+0.367	+0.304	-0.238	-0.075	+0.355	-0.118	-0.118	-0.055
Cypress spurge	-0.230	-0.446	-0.476	-0.516	-0.230	-0.241	+0.090	-0.097	-0.028	+0.076	+0.381	+0.276	+0.333	+0.197	+0.129	-0.360	-0.137	+0.250	+0.081	+0.081	+0.189
Cuckoo flower	-0.540	-0.376	-0.149	-0.692	-0.193	-0.141	+0.224	-0.014	-0.033	-0.024	-0.007	+0.385	+0.218	+0.336	+0.273	+0.322	+0.549	+0.433	+0.194	+0.194	+0.337
Garlic mustard	-0.379	-0.559	-0.513	-0.622	-0.426	-0.269	+0.080	+0.097	-0.013	+0.191	+0.222	+0.482	+0.422	+0.426	+0.267	-0.222	+0.094	+0.297	+0.042	+0.042	+0.137

Table 4 (continued)

	NAO DJFM	TAVG Jan	TAVG Feb	TAVG Mar	TAVG Apr	TAVG May	PREC Jan	PREC Feb	PREC Mar	PREC Apr	PREC May	SNOW Jan	SNOW Feb	SNOW Mar	SNOW Apr	RH Jan	RH Feb	RH Mar	RH Apr	RH MAY
Common sedge	-0.472	-0.580	-0.613	-0.591	+0.020	-0.311	+0.209	+0.088	+0.282	+0.092	+0.311	+0.663	+0.508	+0.563	+0.358	+0.351	+0.249	+0.449	+0.055	+0.401
White deadnettle	-0.482	-0.360	-0.378	-0.662	-0.257	-0.233	+0.164	+0.223	-0.086	+0.154	+0.139	+0.327	+0.402	+0.516	+0.437	+0.098	+0.211	+0.409	+0.143	+0.157
Celandine	-0.297	-0.422	-0.534	-0.645	-0.507	-0.315	+0.136	-0.110	-0.075	+0.111	+0.292	+0.318	+0.201	+0.203	+0.120	-0.136	+0.195	+0.352	+0.134	+0.190
Wayfaring tree	-0.438	-0.460	-0.547	-0.643	-0.377	-0.018	-0.065	-0.083	+0.039	+0.179	+0.069	+0.231	+0.353	+0.350	+0.384	-0.148	-0.120	+0.451	+0.067	-0.077
Common bugle	-0.202	-0.303	-0.414	-0.681	-0.120	-0.159	+0.204	-0.047	+0.044	-0.156	-0.022	+0.245	+0.320	+0.303	-0.001	-0.170	+0.175	+0.281	-0.101	+0.035
Common lilac	-0.415	-0.421	-0.480	-0.556	-0.099	-0.187	+0.187	-0.026	-0.052	+0.005	+0.174	+0.423	+0.223	+0.153	+0.167	-0.156	+0.158	+0.392	+0.102	+0.117
European bird cherry	-0.532	-0.204	-0.583	-0.394	-0.443	-0.316	+0.207	-0.185	-0.168	-0.050	+0.204	+0.251	+0.307	+0.380	+0.259	+0.094	+0.055	+0.421	+0.181	+0.246
Cherry laurel	-0.568	-0.379	-0.459	-0.488	-0.360	+0.126	+0.141	-0.103	+0.001	+0.289	+0.047	+0.112	+0.126	+0.051	+0.000	+0.210	-0.099	+0.316	+0.178	-0.040
Common snowberry	-0.181	-0.427	-0.442	-0.348	-0.491	-0.294	+0.151	+0.144	+0.018	+0.029	+0.343	+0.325	+0.305	+0.269	+0.165	-0.103	+0.072	+0.393	+0.073	+0.173
Horse chestnut	-0.329	-0.400	-0.353	-0.429	-0.705	-0.344	-0.021	-0.045	-0.129	+0.108	+0.115	+0.306	+0.073	+0.107	+0.212	+0.028	+0.117	+0.307	+0.227	+0.062
Woodland strawberry	-0.169	-0.484	-0.367	-0.641	-0.351	-0.180	-0.075	-0.019	+0.035	+0.170	+0.013	+0.433	+0.243	+0.347	+0.220	+0.085	+0.105	+0.338	+0.210	+0.010
Whitotop	-0.310	-0.480	-0.279	-0.530	-0.522	-0.004	-0.035	+0.136	+0.148	+0.399	+0.032	+0.334	+0.190	+0.268	+0.123	-0.090	+0.039	+0.326	+0.191	-0.203
Shrubby cinquefoil	-0.191	-0.173	-0.661	-0.332	-0.419	-0.524	+0.093	-0.084	-0.177	+0.444	+0.466	+0.198	+0.359	+0.431	+0.272	-0.158	-0.001	+0.457	+0.198	+0.363
Showy buttercup	-0.047	-0.366	-0.423	-0.383	-0.657	-0.363	-0.006	-0.213	-0.292	+0.389	+0.309	+0.259	+0.101	+0.090	+0.000	+0.039	+0.134	+0.430	+0.425	+0.264
Ramsons	-0.241	-0.522	-0.463	-0.415	-0.430	-0.003	+0.112	-0.202	-0.208	+0.286	+0.162	+0.448	+0.245	+0.398	+0.147	+0.268	+0.048	+0.168	+0.047	+0.071
Crambe	-0.152	-0.549	-0.371	-0.618	-0.163	-0.392	+0.220	+0.030	-0.151	-0.137	+0.244	+0.540	+0.317	+0.174	-0.017	-0.091	+0.377	+0.199	+0.125	+0.162
French tamarisk	-0.187	-0.250	-0.422	-0.323	-0.710	-0.541	+0.016	-0.154	-0.125	-0.066	+0.313	+0.213	+0.181	+0.012	+0.036	-0.062	+0.103	+0.284	+0.167	+0.332
Common comfrey	-0.193	-0.265	-0.495	-0.414	-0.453	-0.201	-0.059	+0.004	+0.167	+0.080	+0.182	+0.246	+0.207	+0.207	+0.234	+0.010	+0.149	+0.550	+0.167	+0.005
European mountain ash	-0.434	-0.484	-0.213	-0.367	-0.563	-0.402	+0.205	+0.104	-0.060	-0.273	+0.142	+0.422	+0.385	+0.165	+0.213	+0.146	+0.204	+0.298	+0.065	+0.363
Midland hawthorn	-0.044	-0.236	-0.461	-0.240	-0.721	-0.449	-0.299	-0.098	-0.059	+0.228	+0.063	-0.012	+0.115	-0.026	+0.041	-0.101	+0.045	+0.332	+0.392	+0.181
Field chickweed	-0.248	-0.277	-0.488	-0.128	-0.423	-0.649	-0.167	+0.083	-0.546	-0.372	+0.247	-0.068	+0.738	+0.006	-0.027	+0.004	+0.570	+0.053	+0.250	+0.516
Bladder campion	-0.143	-0.318	-0.507	-0.374	-0.580	-0.425	-0.163	-0.182	-0.194	+0.337	+0.165	+0.177	+0.153	+0.233	+0.198	+0.025	+0.014	+0.306	+0.355	+0.098
Red clover	-0.029	-0.174	-0.278	-0.380	-0.502	-0.183	-0.118	-0.194	+0.017	+0.562	+0.092	+0.087	+0.041	+0.044	+0.173	-0.163	-0.270	+0.024	+0.203	-0.231
Ragged Robin	-0.159	-0.195	-0.200	-0.366	-0.343	-0.259	+0.023	+0.005	+0.282	+0.194	+0.283	+0.282	+0.198	+0.081	+0.118	-0.101	+0.011	+0.498	+0.056	-0.028
Ox-eye daisy	-0.128	-0.203	-0.243	-0.304	-0.441	-0.446	-0.239	-0.102	-0.049	+0.358	+0.159	+0.002	+0.241	+0.216	+0.211	+0.089	+0.152	+0.247	+0.315	+0.036
Introduced sage	-0.039	-0.463	-0.304	-0.402	-0.570	-0.377	-0.072	-0.039	-0.182	+0.111	+0.156	+0.396	+0.173	+0.107	+0.271	-0.123	+0.141	+0.370	+0.285	+0.115
Birthwort	-0.151	-0.020	-0.451	-0.004	-0.472	-0.549	-0.180	-0.305	-0.285	+0.203	+0.141	+0.094	+0.228	+0.247	+0.275	+0.023	-0.194	+0.098	+0.358	+0.210
Yellow mignonette	0.217	-0.109	-0.038	-0.473	-0.515	-0.109	-0.151	-0.312	+0.066	+0.360	-0.026	+0.069	-0.131	+0.411	+0.123	+0.165	-0.080	+0.463	+0.316	-0.083
Purple mullein	-0.048	-0.367	-0.374	-0.403	-0.541	-0.547	+0.061	-0.119	-0.256	-0.035	+0.258	+0.288	+0.160	+0.182	+0.013	-0.095	+0.264	+0.240	+0.098	+0.261
Europ. Black elderberry	-0.190	-0.397	-0.288	-0.531	-0.622	-0.572	+0.174	+0.038	-0.279	+0.104	+0.267	+0.385	+0.319	+0.176	+0.134	-0.042	+0.278	+0.355	+0.239	+0.361
Red dogwood	+0.200	+0.254	-0.437	-0.083	-0.368	-0.221	-0.242	-0.081	+0.038	+0.121	+0.027	-0.042	+0.012	-0.083	-0.000	-0.217	-0.423	+0.167	+0.189	-0.183
Corn poppy	-0.182	-0.267	-0.328	-0.379	-0.463	-0.294	-0.012	-0.013	-0.167	+0.515	+0.150	-0.062	+0.387	+0.338	+0.540	-0.084	-0.164	+0.381	+0.190	+0.135
Black locust tree	-0.255	-0.287	-0.254	-0.311	-0.707	-0.725	+0.097	-0.003	-0.184	+0.209	+0.293	+0.235	+0.235	+0.250	+0.115	+0.031	+0.320	+0.443	+0.514	+0.434
Yellow flag	-0.175	-0.268	-0.165	-0.375	-0.592	-0.564	+0.149	+0.079	-0.242	+0.117	+0.083	+0.277	+0.133	+0.233	+0.204	+0.049	+0.431	+0.321	+0.366	+0.347
Cock's-foot	-0.208	-0.242	-0.398	-0.302	-0.541	-0.323	+0.251	-0.009	-0.234	+0.317	+0.453	+0.329	+0.334	+0.086	-0.030	-0.198	-0.163	+0.312	-0.008	+0.068

**Table 4** (continued)

	NAO			TAVG			PREC			SNOW			RH							
	DJFM	Jan	Feb	Mar	Apr	May	Jan	Feb	Mar	Apr	May	Jan	Feb	Mar	Apr	May				
Dog rose	-0.322	-0.475	-0.461	-0.614	-0.735	-0.666	-0.023	+0.081	-0.226	+0.058	+0.223	+0.465	+0.364	+0.455	+0.492	-0.168	+0.241	+0.509	+0.387	+0.272
Oleaster	-0.254	-0.312	-0.414	-0.516	-0.592	-0.783	+0.075	-0.009	-0.182	+0.142	+0.516	+0.319	+0.301	+0.294	+0.070	-0.116	+0.193	+0.230	+0.387	+0.508
Common privet	+0.231	-0.001	+0.117	-0.272	-0.539	-0.543	-0.165	+0.007	-0.118	+0.085	+0.272	+0.091	-0.057	+0.002	-0.239	-0.015	+0.389	+0.370	+0.418	+0.276
Littleleaf linden	+0.047	-0.128	-0.175	-0.249	-0.522	-0.519	+0.066	-0.022	-0.222	+0.155	+0.398	+0.183	+0.154	-0.066	-0.253	-0.097	+0.038	+0.292	+0.224	+0.225
Goatsbeard	+0.250	+0.053	-0.090	+0.171	-0.347	-0.413	-0.144	-0.276	+0.031	+0.171	-0.038	-0.116	-0.048	-0.005	-0.263	-0.417	-0.224	+0.188	+0.376	-0.090
Spanish chestnut	-0.110	-0.001	+0.047	-0.303	-0.318	-0.679	+0.004	+0.200	+0.105	+0.191	+0.024	-0.097	-0.052	+0.658	-0.000	-0.014	+0.403	+0.488	+0.566	+0.288
Common viper's bugloss	+0.151	-0.159	+0.290	-0.038	-0.393	-0.457	-0.159	+0.090	+0.084	+0.573	-0.312	+0.008	-0.015	+0.183	-0.000	-0.058	+0.190	+0.092	+0.477	-0.033
Yucca	-0.220	-0.312	-0.295	-0.248	-0.576	-0.598	-0.244	+0.251	-0.204	+0.425	+0.369	+0.208	+0.339	+0.307	+0.292	-0.011	+0.202	+0.194	+0.369	+0.231
Southern catalpa	+0.064	-0.004	+0.094	-0.054	-0.645	-0.676	-0.144	+0.007	-0.255	+0.258	+0.107	-0.041	+0.053	+0.077	+0.059	+0.235	+0.227	+0.247	+0.454	+0.362
Pagodia tree	+0.107	-0.338	+0.210	-0.082	-0.206	-0.080	-0.401	-0.215	+0.045	+0.006	-0.339	+0.265	-0.022	-0.075	+0.569	-0.034	+0.264	-0.026	+0.340	-0.065

Significant ( $P < 0.05$ ) correlation values are printed in bold

NAO North Atlantic Oscillation, TAVG average temperature, PREC precipitation, SNOW snow cover, RH relative humidity of the air

higher than that with the winter NAO, e.g., in two-leaf squill, lesser celandine, yellow star-of-Bethlehem, cherry plum, corydalis, cowslip primrose, apricot, garlic mustard, and common sedge. Moreover, flowering in a number of species correlated significantly with temperature, but not with the winter NAO index, e.g., yellow marsh marigold, spring pea, common pear, cypress spurge, celandine, common bugle, woodland strawberry, whitetop, ramsons, crambe, tamarisk, common comfrey, Midland hawthorn, bladder campion, and purple murein. It is therefore reasonable to consider local air temperature as a more important factor in the flowering events than the remote NAO. A significant correlation of phenological events with monthly precipitation was much less frequent (Table 4). On the other hand, snow cover obviously plays an important role in delaying start of flowering, due to a combined effect of temperature and precipitation (Table 4). Also, relative humidity of the air seems to affect flowering events in many species, especially in March: The higher the humidity, the later the flowering observed in sweet violet, cherry plum, corydalis, yellow anemone, apricot, cowslip primrose, Norway maple, blackthorn, common dandelion, cherry, southern magnolia, common pear, common apple, cuckoo flower, white deadnettle, wayfaring tree, showy buttercup, common comfrey, ragged robin, black locust tree, etc. (Table 4).

### Discussion

Air temperature is a very important factor in determining the beginning of the growing season and in the phenology of plant flowering, and average air temperature in Europe (except for southern Europe) is correlated with the NAO index (Sparks et al. 2000; Chmielewski and Rötzer 2001; D'Odorico et al. 2002; Aasa et al. 2004; Ahas and Aasa 2006). This was confirmed in this study as well: Local temperature is obviously a proximate factor in plant phenology, while the winter NAO is the ultimate factor, affecting temperature and other meteorological phenomena in Central Europe mainly during the spring season.

The current study showed that plant species flowering in early spring started earlier after positive winter phases of the NAO while later-flowering (midseason) plant species were less affected following such warm winters; this is in accord with similar phenological studies in other European countries (Post and Stenseth 1999; Aasa et al. 2004; Ahas and Aasa 2006). For example, Aasa et al. (2004), as part of a wider study, reported significant correlations between the winter NAO index and phenological events in three plant species in Weiz, Austria (47.22 N, 15.63 E; i.e., close to my study area) during 1951–1998. Their correlations (current study data in parentheses) were -0.57 (-0.33) for coltsfoot, -0.46 (-0.42) for common lilac, and -0.37 (-0.47) for silver birch leaf unfolding. Some studies have shown that the effect of the

NAO on plant phenology is more marked in the Baltic states than in Central Europe, with generally larger coefficients of correlation between the winter NAO index and the onset of spring phenological phases (up to  $-0.60$ ; Aasa et al. 2004; Gormsen et al. 2005; Kalvane et al. 2009).

One important question is whether the winter NAO index could be used to forecast the onset of flowering. The answer is yes for certain early-flowering plants, including economically important domesticated trees such as apricot, cherry, peach, and apple. In these species, forecasts could be developed by calculating linear regressions of the beginning of flowering (in Julian days) on the preceding winter NAO index. For the study area and the current dataset, the simple regression models are  $98.0-2.6335$  NAO (apricot),  $106.0-2.1335$  NAO (cherry),  $107.4-1.7182$  NAO (peach), and  $112.7-1.9575$  NAO (apple), where NAO means the value of the preceding winter NAO index (December to March).

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