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Flowering of allergenically important plant species in relation to the North Atlantic Oscillation system and thermal time in the Czech Republic

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Abstract This paper analyses long-term (1960–2015) onset of flowering in 16 native terrestrial plants (11 of them produce important allergens) recorded in different parts of the Czech Republic (southern, central and northern part) in relation to the North Atlantic Oscillation (NAO) index of the preceding winter and thermal data—growing degree-days (GDD) and soil temperature. Flowering occurred significantly earlier following positive winter NAO phases (causing spring to be warmer than normal in Central Europe) in nearly all early-flowering (February, March, April) species; high Pearson correlation values were recorded in, e.g. wood anemone, common snowdrop, goat willow, common hazel and common alder. There was found a difference between the southern and northern part of the country, e.g. in silver birch and pedunculate oak. Out of the later-flowering (May–July) plant species, black elder and meadow foxtail also significantly correlated with the winter NAO index, lime tree correlated less markedly. The best results of a threshold for calculation of GDD to onset of beginning of flowering were found in lime tree—it was 5 °C at all three stations. Results of other taxa were more variable (e.g. 4–7 °C in goat willow; 6–10 °C in silver birch). Pearson correlation coefficients between NAO index and GDD were negative in

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lime tree at all thresholds (5, 6, 7, 8, 9, 10 °C), while goat willow and silver birch were not so uniform (both positive and negative values). Correlation coefficients between phenophase onset and soil temperature (10 cm depth) had the highest values in silver birch, European larch and wood anemone. Stations situated at higher elevation showed negative correlation coefficient with soil temperature in common snowdrop, pedunculate oak, meadow foxtail and lime tree; other values were positive.

Keywords NAO · Allergology · Czech Republic · Onset of flowering · Climate change · GDD · Soil temperature

1 Introduction

Phenology—the timing of seasonal activities of living organisms—is perhaps the simplest method for tracking the response of species to environmental change (Scheifinger and Templ 2016). Together with aeropalynology, they are scientific disciplines/branches that study such natural phenomena as seasonal dynamics of vegetative and generative changes of vegetation and the occurrence of pollen in the air (Hájková et al. 2015). Since the first description of hay fever by John Bostock in 1819, the role of pollen in the pathogenesis of allergic diseases has been well established. The most important allergic diseases are asthma and rhinitis, which affect from 5 to 30% of the population in industrialized countries (Cecchi 2013). Pollen content in the air, which is the result of pollen production and different aerobiological processes, emission, dispersion and/or transport and deposition, is controlled by factors associated with climate. Any change in these factors may affect the phenological and quantitative features of the season (Dahl et al. 2013). Systematic phenological observations can now look back as far as the eighteenth century, when Carolus Linnaeus started the first phenological network in Sweden and Finland 1750–1752 (Nekovář et al. 2008). One of the earliest plant phenological networks covering a greater scale is most likely the first European Phenological Network founded by Hoffmann, Professor of Botany at the University of Giessen, and his student Ihne in 1882 (Hoffmann and Ihne 1882). Plant phenological observations have traditionally been collected in Europe by a network of volunteer observers operated by national meteorological and hydrometeorological services (NHMS).

Facing recent climate changes, phenology has two major functions. Firstly, it reveals measurable impacts of a climate change on flora (and fauna), which at the same time clearly demonstrates global climate change in people's backyards. Secondly, long-term phenological data allow the reconstruction of temperature and its variability in the last centuries (Menzel et al. 2008).

The North Atlantic Oscillation (NAO) index (atmospheric circulation index) describes a major driving force of the northern hemisphere climate system, which largely determines the interannual variation of winter temperatures in the northern Atlantic region (Hurrell 1995). In Europe, NAO seems to be responsible for a large-scale component of climate variability, particularly influencing winter and spring weather conditions, and also, crop production quality and quantity characteristics. The use of NAO information showed great potential for the development of crop production forecasting systems (Menzel et al. 2008). However, the effect of NAO on biota might differ regionally within Europe (Hubálek 2016).

It can be assumed that the onset dates of phenological phases are associated mainly with the temperature changes, which are caused by atmospheric circulation (it describes the impingement of warm or cold air into the study area). The question is: how are plants and in particular, allergenic plants responding to these climatic changes?

The aim of the current study is to investigate whether the NAO index also affects the onset of flowering of plant species (including allergenically important species) in the southern, central and northern part of the Czech Republic. The beginning of flowering in 16 plant species was correlated with the winter NAO index. In addition, the effect of thermal time on the onset of flowering was also evaluated (GDD and 10 cm depth soil temperature) to find out, whether soil temperature is better than air temperature for predicting the beginning of flowering. Another task was to find the best threshold temperature for each plant species.

2 Materials and methods

2.1 Study area

The research was performed in the southern, northern and central part of the Czech Republic, districts: Mlýny, Chřibská, Kostelec nad Labem, Doksany, Hodonín and Lednice (Fig. 1, Table 1). The climate of the region is characterized as follows (Figs. 2, 3, 4).

2.2 Phenological data

Long-term (1960–2015) phenological data were obtained at five phenological stations (as mentioned above—Mlýny, Chřibská, Kostelec nad Labem, Doksany, Hodonín and Lednice) of the Czech Hydrometeorological Institute (CHMI) network. CHMI maintains a network of phenological stations recording phenophases of wild plants following CHMI methodological instructions (Anonymous 2009). From the phenophases observed according to Coufal et al. (2004), only beginning of flowering (10% of flowers open) was concerned in this study.

During this phenophase, catkins are soft and already opened, anthers are fully visible, and 10% of them open and release pollen. Native terrestrial plant species were chosen for the survey (16 in total; allergenic plants are highlighted in bold italic in Tables)—blackthorn (*Prunus spinosa*), black elder (*Sambucus nigra*), cocks foot (*Dactylis glomerata*), coltsfoot (*Tussilago farfara*), common alder (*Alnus glutinosa*), common hazel (*Corylus avellana*), common snowdrop (*Galanthus nivalis*), European beech (*Fagus sylvatica*), European larch (*Larix decidua*), goat willow (*Salix caprea*), lime tree (*Tilia cordata*), meadow foxtail (*Alopecurus pratensis*), midland hawthorn (*Crataegus laevigata*), pedunculate oak (*Quercus robur*), silver birch (*Betula pendula*), scotch pine (*Pinus sylvestris*) and wood anemone (*Anemone nemorosa*). The species were observed in one plant community (the same varieties); uniform landform and plant were growing in optimal living conditions. At least five (from 5 to 10) healthy individuals are usually monitored at each observations site. Calendar dates of phenological events were transformed into Julian days.

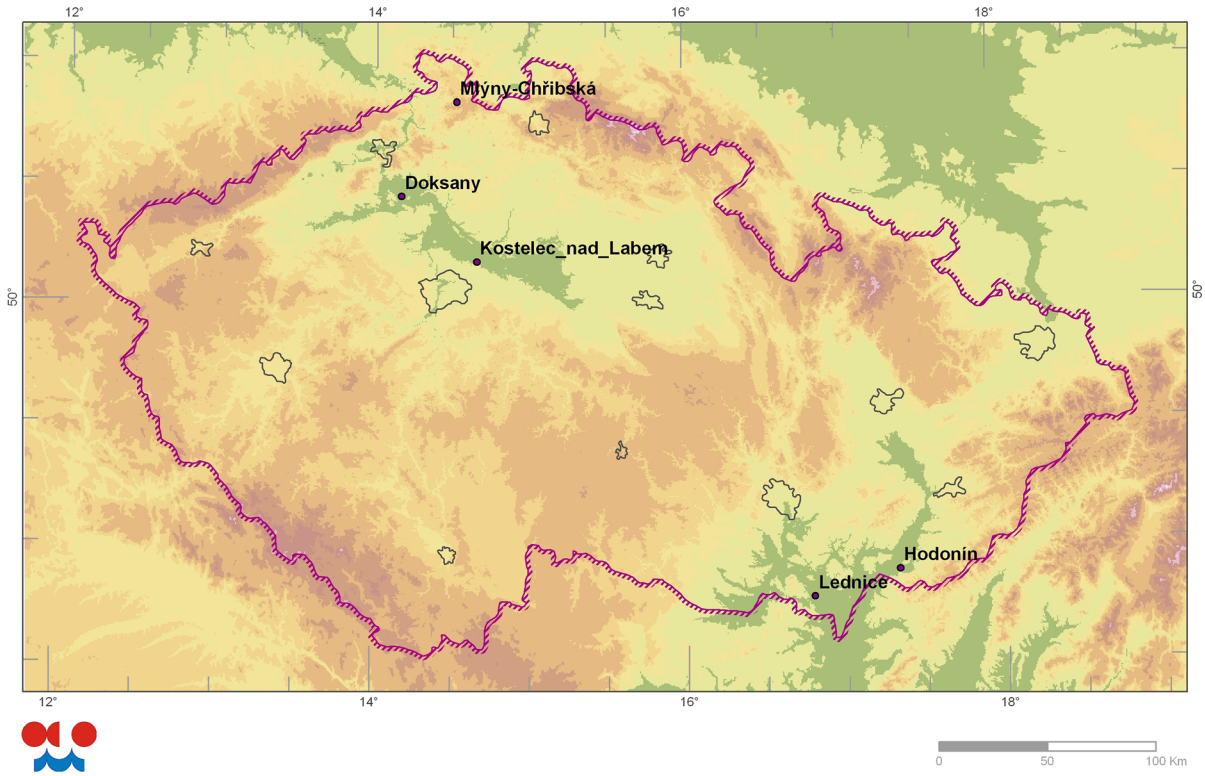


Fig. 1 Map of phenological stations

Table 1 Characteristics of phenological (P) and climatological (C) stations

Station	Altitude (m a.s.l.)	Longitude	Latitude
Hodonín/Lednice (P)	150–200	16°30′–17°00′ E	48°40′–49°05′ N
Doksany/Kostelec n. L. (P)	155–169	14°10′–14°35′E	50°14′–50°27′N
Mlýny/Chřibská (P)	350–410	14°29′–14°30′E	50°49′–50°52′N
Varnsdorf (C)	367	14°36′E	50°54′N
Lednice (C)	177	16°47′E	48°47′N
Doksany (C)	158	14°10′E	50°27′N

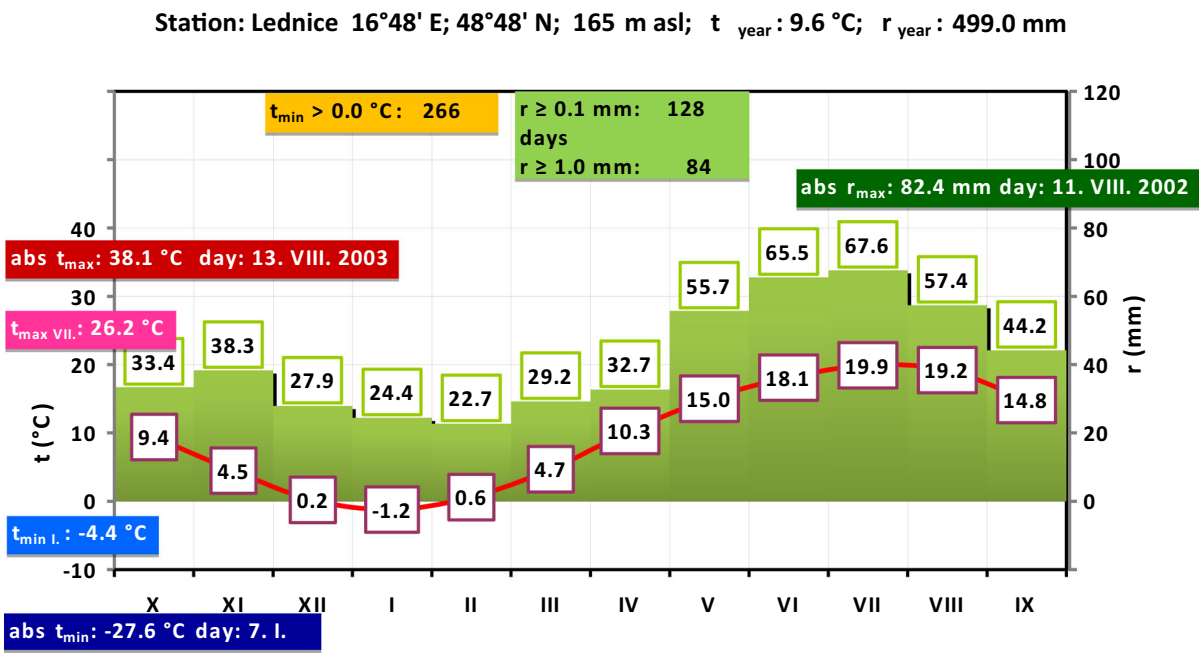


Fig. 2 Climagram of Lednice station

2.3 North Atlantic Oscillation data

Winter (December–March) NAO indices for the study years were obtained from (Hurrell (1995). This index is calculated 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 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 frequent 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 shows the opposite pattern of air 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 (Hurrell 1995; Hubálek 2016).

2.4 Climatic data and statistical analysis

To compare the phenological predicting accuracy when using air and soil temperature as predictors we obtained also soil temperature data at 10 cm depth (CHMI database).

Thermal time (cumulative heat), often expressed in growing degree-days (GDD), was calculated as follows (Sobíšek et al. 1993):

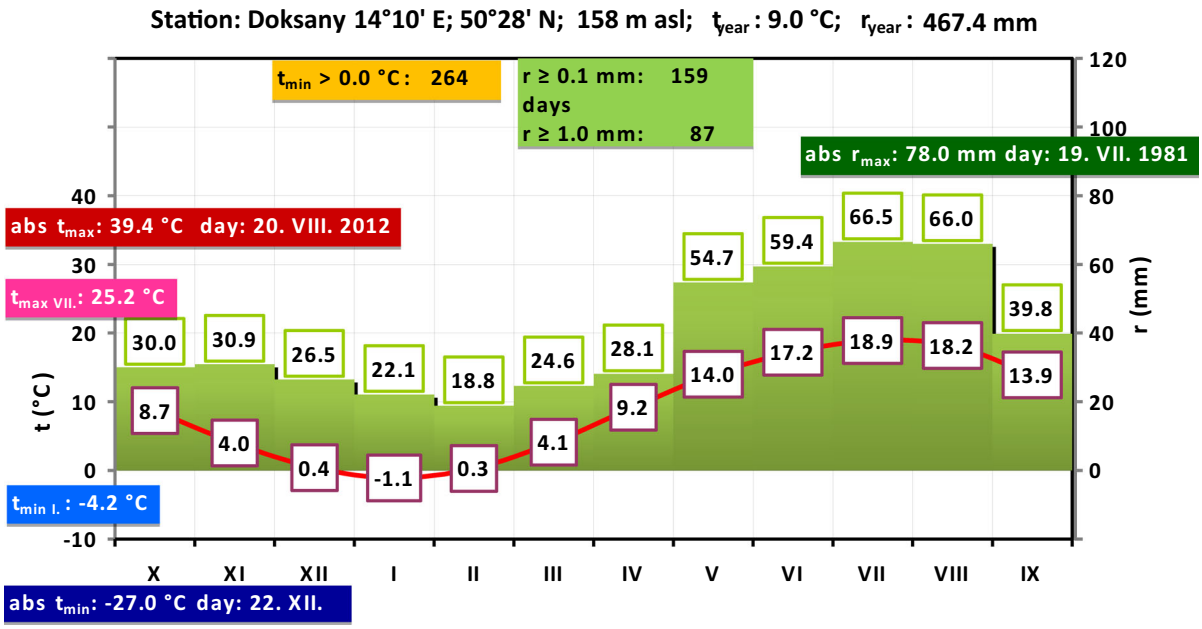


Fig. 3 Climagram of Doksany station

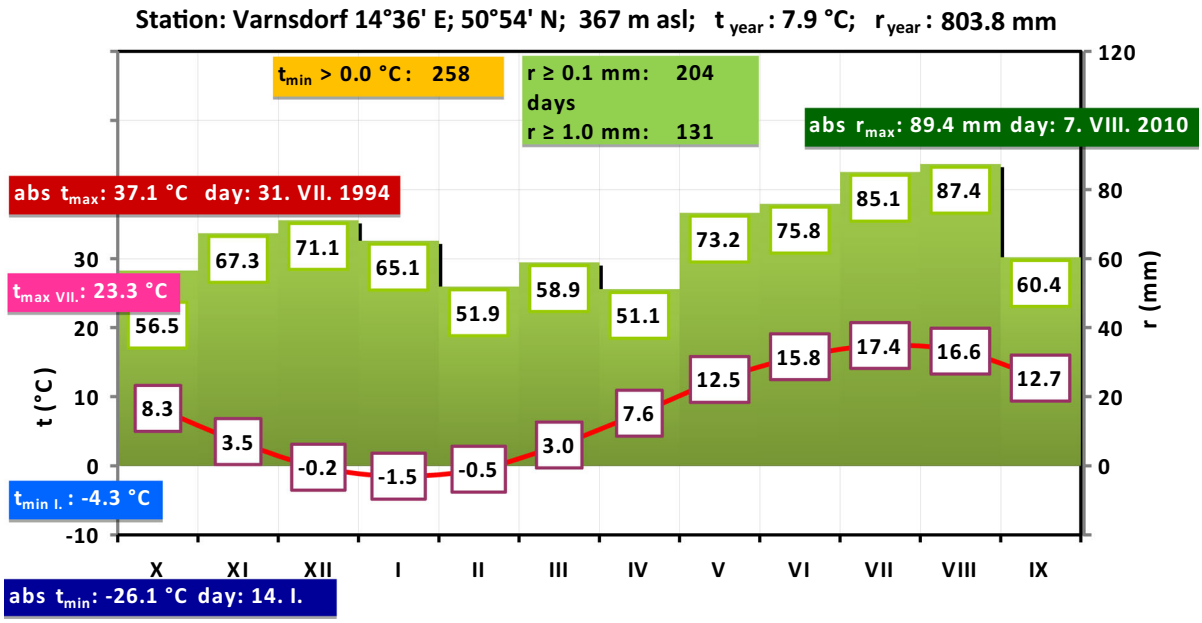


Fig. 4 Climagram of Varnsdorf station

$$T_{\text{avg}} = (T07 + T14 + 2 \times T21)/4$$

where $T07$, $T14$ and $T21$ mean air temperature at 7, 14 and 21, respectively

$$\text{GDD} = T_{\text{avg}} - T_{\text{base}}$$

T_{base} = temperature threshold

If $T_{\text{avg}} < T_{\text{base}}$ then $T_{\text{avg}} = T_{\text{base}}$

T_{base} = 3 °C (TS3), 4 °C (TS4), 5 °C (TS5), 6 °C (TS6), 7 °C (TS7), 8 °C (TS8), 9 °C (TS9) and 10 °C (TS10).

GDD were calculated as the most suitable meteorological characteristics using phenological data. Goat willow (pre-early spring flowering taxa), silver birch (spring flowering taxa) and lime tree (early-summer flowering taxa) were chosen into this thermal time calculation to find the best threshold (T_{base}) for each taxa. Daily mean air temperature data were obtained from the CHMI meteorological stations closest to the appropriate phenological station. Climatic data series were quality checked, homogenized, and the missing values were filled using AnClim (Štěpánek 2010a), LoadData and ProClimDB (Štěpánek 2010b) software packages.

PCC was used to examine the linear relationships between the winter NAO index, climatic parameters and phenological events of each plant species. The analysis was performed in Microsoft Excel. The climate conditions of each locality are characterized by climagrams (Figs. 2, 3, 4). We used a modified Walter–Lieth climagram (e.g. Kožnarová et al. 1997; Kožnarová and Klabzuba 2010; Kožnarová et al. 2011) based on the long-term average data 1961–2010.

3 Results

The onset and duration of phenological phases in plants differed considerably between the years, and statistical characteristics are given in Tables 2, 3, 4 including Pearson's correlation coefficient (r). A significant ($P < 0.05$) correlation between flowering and winter NAO index was found in 11 species (Hodonín/Lednice station), 10 species (Kostelec nad Labem/Doksany station) and 14 species (Mlýny/Chřibská station) of the 16 species tested. The largest correlation coefficients were obtained at Hodonín/Lednice station in *Alnus glutinosa* (− 0.502), at Kostelec nad Labem/Doksany station in *Corylus avellana* (− 0.582) and at Mlýny/Chřibská station in *Galanthus nivalis* (− 0.636). Chronological order of beginning of flowering was not the same in all species at tested stations; there were small differences among them (e.g. silver birch and European larch, scotch pine and meadow foxtail, goat willow and common hazel).

Nearly all pre-early spring flowering plant species (February–March) had significant negative correlations with the winter NAO index (Tables 5, 6, 7), and markedly high r values, $|r| > 0.5$, were recorded for common snowdrop, common hazel, common alder and goat willow. This indicates nearly 25% of the variability in the start of flowering of these plant species is attributable to the NAO index. Species blooming in April had significant correlations with the winter NAO index, and markedly high r values were found in blackthorn (− 0.511 at Hodonín/Lednice station and − 0.597 at Kostelec nad Labem/Doksany station). In contrast, the later-flowering plant species (those flowering in May, June and July) have the lowest proportion of significant correlations with the winter NAO index, except for species blooming in June and July at Hodonín/Lednice and Mlýny/Chřibská stations (lime tree, cocks foot and black elder). Changes in beginning of flowering of each species in particular decades are given in Tables 8, 9, 10.

Results of Pearson correlation coefficient (r) between NAO index and sums of GDD in goat willow, silver birch and lime tree are given in Tables 11 and 12; results of Pearson correlation coefficient (r) between onset of phenological stage and sums of GDD in goat willow, silver birch and lime tree are in Tables 13 and 14.

Table 15 shows Pearson correlation coefficient (r) between phenophase onset and soil temperature (at 10 cm). The highest values were found in European larch (0.773 at Hodonín/Lednice station), wood anemone (0.825 at Kostelec/Doksany station) and silver birch (0.644 at Mlýny/Chřibská station). Some coefficients are negative, e.g. in common snowdrop, pedunculate oak, meadow foxtail and lime tree. Results of average soil temperature at beginning of flowering onset are reported in Table 16. The highest differences among stations were found, e.g. in wood anemone, silver birch and blackthorn.

4 Discussion

The onset and duration of phenological phases in plants differed considerably between the years. Together with genetics factors, air temperature and soil temperature are critical for the start of spring phenological phases (Bednářová and Kučera 2002). NAO is one of the dominant factors controlling (above all winter and spring) climate over Europe.

High Pearson correlation values were recorded in, e.g. wood anemone, common snowdrop, goat willow,

Table 2 Mean flowering date of 16 plant species (Mean, Julian days) in *n* recorded years, and correlation (*r*, Pearson's product-moment coefficient) with winter NAO index—Hodonín/Lednice station

Species are arranged in order of mean date (Julian dates). Allergenically important species are highlighted in bold italic

SD standard deviation

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

Plant species	*n*	Mean	Min	Max	SD	*r*
Galanthus nivalis	56	57	28	83	11.34	**− 0.380**
Corylus avellana	55	59	12	93	19.44	**− 0.383**
Alnus glutinosa	53	74	37	108	15.16	**− 0.502**
Tussilago farfara	55	76	50	100	11.94	− 0.214
Salix caprea	56	82	39	102	13.01	**− 0.347**
Anemone nemorosa	51	99	68	123	15.01	**− 0.277**
Betula pendula	56	100	79	115	8.12	− 0.247
Larix decidua	53	101	71	133	15.8	− 0.165
Prunus spinosa	55	102	82	115	8.33	**− 0.511**
Quercus robur	55	116	98	134	9.45	**− 0.306**
Crataegus laevigata	56	127	99	145	9.71	**− 0.503**
Alopecurus pratensis	51	132	102	159	12.91	− 0.227
Pinus sylvestris	55	132	111	157	9.07	**− 0.322**
Sambucus nigra	56	139	107	159	9.58	**− 0.377**
Dactylis glomerata	51	144	120	163	11.38	− 0.260
Tilia cordata	54	165	124	185	10.26	**− 0.332**

Table 3 Mean flowering date of 16 plant species (Mean, Julian days) in n recorded years, and correlation (*r,* Pearson's product-moment coefficient) with winter NAO index—Kostelec nad Labem/Doksany station

Species are arranged in order of mean date. Allergenically important species are highlighted in bold italic

SD standard deviation

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

Plant species	*n*	Mean	Min	Max	SD	*r*
Galanthus nivalis	56	60	20	89	14.55	**− 0.532**
Corylus avellana	56	61	10	97	21.19	**− 0.582**
Alnus glutinosa	54	67	9	107	22.14	**− 0.459**
Tussilago farfara	40	80	53	100	11.44	− 0.150
Salix caprea	37	80	41	101	13.16	**− 0.506**
Larix decidua	20	102	71	133	17.09	0.039
Betula pendula	51	103	56	119	10.36	**− 0.433**
Prunus spinosa	39	105	71	122	11.36	**− 0.597**
Anemone nemorosa	30	110	68	137	17.7	− 0.127
Quercus robur	28	123	103	141	10.83	− 0.325
Pinus sylvestris	28	126	114	140	5.94	− 0.027
Crataegus laevigata	39	129	98	144	8.95	**− 0.545**
Alopecurus pratensis	41	137	110	163	12.11	**− 0.374**
Dactylis glomerata	52	143	125	163	9.04	**− 0.421**
Sambucus nigra	56	144	126	166	8.58	**− 0.470**
Tilia cordata	50	167	134	190	10.9	− 0.232

common hazel and common alder. In contrast, there was a big difference in values of Pearson correlation between the southern (higher values) and northern part (lower values) of the Czech Republic, e.g. in silver birch and pedunculate oak. This underlines how changes in atmospheric circulation can have a great influence on the pollination of many plants with consequences in various sectors including public health (allergology). Hubálek (2016) mentioned that local temperature is 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. This was confirmed in the present study as well.

The timing of phenological phases is influenced by different environmental factors, such as temperature of the external environment, moisture and radiation

Table 4 Mean flowering date of 16 plant species (Mean, Julian days) in n recorded years, and correlation (*r,* Pearson's product-moment coefficient) with winter NAO index—Mlýny/Chřibská station

Species are arranged in order of mean date. Allergenically important species are highlighted in bold italic

SD standard deviation

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

Plant species	*n*	Mean	Min	Max	SD	*r*
Galanthus nivalis	56	69	36	104	15.88	**− 0.636**
Corylus avellana	56	76	36	106	16.83	**− 0.530**
Salix caprea	56	86	41	123	17.98	**− 0.507**
Alnus glutinosa	55	86	49	113	13.82	**− 0.477**
Tussilago farfara	56	88	56	113	12.58	**− 0.481**
Anemone nemorosa	56	94	61	114	9.74	**− 0.454**
Larix decidua	53	111	79	143	12.25	**− 0.291**
Betula pendula	50	117	93	138	10.14	− 0.163
Prunus spinosa	55	123	100	145	9.43	**− 0.300**
Pinus sylvestris	55	137	110	162	13.44	**− 0.303**
Quercus robur	55	139	120	157	7.8	− 0.176
Alopecurus pratensis	53	140	122	159	7.68	**− 0.462**
Crataegus laevigata	55	142	124	163	10.28	**− 0.421**
Dactylis glomerata	56	158	129	187	13.32	**− 0.307**
Sambucus nigra	56	160	141	178	9.51	**− 0.507**
Tilia cordata	54	191	160	218	15.55	**− 0.320**

Table 5 Mean Pearson correlation coefficients (*r*) between the winter NAO index and onset of flowering of 16 plant species—Hodonín/Lednice station

	No. of plant species	No. of significant correlations	Mean overall *r* value
February	2	2	− 0.382
March	3	2	− 0.354
April	5	3	− 0.301
May	5	3	− 0.338
June	1	1	− 0.332

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

Table 6 Mean Pearson correlation coefficients (*r*) between the winter NAO index and onset of flowering of 16 plant species—Kostelec/Doksany station

	No. of plant species	No. of significant correlations	Mean overall *r* value
February	1	1	− 0.532
March	4	3	− 0.424
April	4	3	− 0.279
May	6	3	− 0.360
June	1	0	− 0.232

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

Table 7 Mean Pearson correlation coefficients (*r*) between the winter NAO index and onset of flowering of 16 plant species—Mlýny/Chřibská station

	No. of plant species	No. of significant correlations	Mean overall *r* value
March	5	5	− 0.489
April	3	2	− 0.303
May	5	4	− 0.332
June	2	2	− 0.407
July	1	1	− 0.320

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

Table 8 Average date of beginning of flowering onset in particular decades (Julian dates)

	Common hazel			Common alder			Goat willow		
	1	2	3	1	2	3	1	2	3
1961–1970	65	73	88	77	80	91	87	79	104
1971–1980	53	64	79	72	72	89	80	84	94
1981–1990	76	67	79	80	82	88	92	77	97
1991–2000	54	55	74	60	58	84	79	79	68
2001–2010	60	55	67	74	53	81	75	–	71

1 Hodonín/Lednice

2 Kostelec/Doksany

3 Mlýny/Chřibská

Table 9 Average date of beginning of flowering onset in particular decades (Julian dates)

1 Hodonín/Lednice
2 Kostelec/Doksany
3 Mlýny/Chřibská

	Silver birch			Pedunculate oak			European larch		
	1	2	3	1	2	3	1	2	3
1961–1970	101	105	120	123	–	143	103	No data	114
1971–1980	95	102	122	122	137	145	96	No data	104
1981–1990	108	99	120	120	126	141	113	No data	105
1991–2000	100	101	118	110	112	135	98	102	118
2001–2010	97	107	111	114	129	133	95	101	114

Table 10 Average date of beginning of flowering onset in particular decades (Julian dates)

1 Hodonín/Lednice
2 Kostelec/Doksany
3 Mlýny/Chřibská

	Meadow foxtail			Cocks foot			Lime tree		
	1	2	3	1	2	3	1	2	3
1961–1970	141	143	141	149	151	167	171	170	202
1971–1980	141	145	145	148	147	168	169	177	205
1981–1990	141	147	139	155	144	166	165	168	203
1991–2000	121	122	136	137	137	139	167	167	175
2001–2010	127	137	141	138	139	153	161	160	180

Table 11 Pearson correlation coefficient (r) between NAO index and sums of GDD in goat willow (*Salix caprea*)

	TS3	TS4	TS5	TS6	TS7
Hodonín/Lednice	**0.426**	0.220	0.218	0.236	0.264
Kostelec/Doksany	**0.335**	0.236	0.190	0.143	0.118
Mlýny/Chřibská	0.025	− 0.075	-0.173	-0.229	**− 0.261**

Bold indicates very high significance

regime, soil conditions and landscape features. The dynamics of climatic factors are mostly determined by atmospheric circulation controlling the temperature regime, which is the most important trigger of phenological phases in temperate ecosystems (Schwartz 2003). Some authors, e.g. Emberlin et al. (1997), found a trend for *Betula* start date to be earlier by one day every two years as a consequence of an increase of temperatures in January–March period in recent years. Our study confirmed earlier onset of *Betula* flowering in the southern and northern part of the Czech Republic (Table 9).

The average sums of GDD for beginning of flowering in goat willow, silver birch and lime tree are listed in Tables 17 and 18. Many authors have also studied the onset of spring phenophases in relation to temperature sums, e.g. Škvareninová (2007, 2008). Average sums of GDD in goat willow are higher in the southern part of the country, in silver birch the values in the southern, central and northern part of the country are very similar and in the late flowering taxa—lime tree, in contrast the highest differences in GDD are in the north (Mlýny/Chřibská station).

McMaster and Wilhelm (1998) investigated if the soil temperature is better predictor of phenological stages than air temperature, but the results did not support their hypothesis. A similar output was obtained.

All tested inputs could be useful in a phenological model, but it is important to test soil temperature also at other depths (e.g. 5, 20 cm, etc.). And the question is—is one phenological model enough for the Czech Republic? The results show the need to create more phenological models for different parts of the Czech Republic.

Table 12 Pearson correlation coefficient (r) between NAO index and sums of GDD in silver birch (*Betula pendula*) and lime tree (*Tilia cordata*)

Station/species	TS5		TS6		TS7		TS8		TS9		TS10	
	Betula pendula	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*
1	0.277	− 0.247	0.201	− 0.286	0.150	− 0.310	0.075	− 0.322	0.092	− 0.334	0.059	**− 0.340**
2	0.047	− 0.110	− 0.030	− 0.150	− 0.109	− 0.179	− 0.152	**− 0.192**	− 0.171	− 0.194	− 0.185	**− 0.192**
3	0.189	− 0.148	0.140	− 0.159	0.101	**− 0.163**	0.073	− 0.160	0.049	− 0.154	0.031	− 0.146

Bold indicates very high significance

1. Hodonín/Lednice
2. Kostelec/Doksany
3. Mlýny/Chřibská

Table 13 Pearson correlation coefficient (*r*) between phenophase onset and sums of GDD in goat willow (*Salix caprea*)

	TS3	TS4	TS5	TS6	TS7
Hodonín/Lednice	0.179	0.220	0.218	0.236	**0.264**
Kostelec/Doksany	0.053	**0.297**	0.296	0.285	0.275
Mlýny/Chřibská	0.390	0.406	0.435	**0.439**	0.426

Bold indicates very high significance

5 Conclusions

The results of phenological observations during 1960–2015 show considerable interannual differences in beginning of flowering of specific plants at particular stations (localities). Chronological order of beginning of flowering is not the same in all taxa; there are small time differences among tested stations (e.g. in silver birch and European larch, scotch pine and meadow foxtail, goat willow and common hazel). Flowering occurred significantly earlier following positive winter NAO phases (causing spring to be warmer than it is normal in Central Europe) in nearly all early-flowering (February, March, April) species; high Pearson correlation values were recorded in, e.g. wood anemone, common snowdrop, goat willow, common hazel and common alder. In contrast, there

Table 14 Pearson correlation coefficient (*r*) between phenophase onset and sums of GDD in silver birch (*Betula pendula*) and lime tree (*Tilia cordata*)

Station/species	TS5		TS6		TS7		TS8		TS9		TS10	
	Betula pendula	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*
1	0.246	**0.732**	0.265	0.723	**0.277**	0.707	0.270	0.687	0.266	0.662	0.267	0.631
2	0.271	**0.465**	0.358	0.444	0.213	0.419	0.388	0.384	0.390	0.342	**0.396**	0.294
3	0.445	**0.631**	**0.450**	0.614	0.446	0.593	0.424	0.564	0.397	0.528	0.381	0.482

Bold indicates very high significance

1. Hodonín/Lednice
2. Kostelec/Doksany
3. Mlýny/Chřibská

Table 15 Pearson correlation coefficient (*r*) between phenophase onset and soil temperature (10 cm depth)

Allergenically important species are highlighted in bold italic

Bold indicates very high significance

Species/station	Hodonín/Lednice	Kostelec/Doksany	Mlýny/Chřibská
Galanthus nivalis	0.116	− 0.122	− 0.087
Corylus avellana	0.355	0.174	0.160
Salix caprea	0.737	0.552	0.518
Alnus glutinosa	0.462	0.406	0.384
Tussilago farfara	0.399	0.355	0.420
Anemone nemorosa	0.697	**0.825**	0.527
Larix decidua	**0.773**	0.800	0.495
Betula pendula	0.382	0.640	**0.644**
Prunus spinosa	0.294	0.534	0.241
Pinus sylvestris	0.654	0.168	0.384
Quercus robur	0.605	0.515	− 0.023
Alopecurus pratensis	0.601	0.551	− 0.195
Crataegus laevigata	0.614	0.559	0.241
Dactylis glomerata	0.280	0.010	0.284
Sambucus nigra	0.431	0.228	0.113
Tilia cordata	0.681	− 0.136	− 0.192

Table 16 Average soil temperature (10 cm depth) at beginning of flowering onset

Species/station	Hodonín/Lednice	Kostelec/Doksany	Mlýny/Chřibská
Galanthus nivalis	1.6	2.0	1.6
Corylus avellana	2.4	3.2	2.9
Salix caprea	5.4	4.7	4.5
Alnus glutinosa	4.0	3.9	4.8
Tussilago farfara	3.8	4.4	4.9
Anemone nemorosa	7.5	9.4	6.2
Larix decidua	8.4	9.6	8.9
Betula pendula	8.4	9.6	10.7
Prunus spinosa	8.5	10.4	11.0
Pinus sylvestris	14.3	14.8	13.2
Quercus robur	10.9	12.7	13.5
Alopecurus pratensis	13.4	15.3	13.9
Crataegus laevigata	13.5	13.7	14.0
Dactylis glomerata	15.6	16.1	15.2
Sambucus nigra	15.0	16.6	15.7
Tilia cordata	18.8	19.5	18.1

Allergenically important species are highlighted in bold italic

Table 17 Average sums of GDD for beginning of flowering in goat willow (*Salix caprea*)

	TS3	TS4	TS5	TS6	TS7
Hodonín/Lednice	83	58	42	28	18
Kostelec/Doksany	74	46	29	17	12
Mlýny/Chřibská	65	44	29	19	12

Table 18 Average sums of GDD for beginning of flowering in silver birch (*Betula pendula*) and lime tree (*Tilia cordata*)

Station/species	TS5		TS6		TS7		TS8		TS9		TS10	
	Betula pendula	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*	*Betula pendula*	*Tilia cordata*
1	100	716	103	626	76	543	55	466	38	395	26	330
2	103	670	99	580	72	497	51	422	34	353	22	290
3	113	793	85	692	63	598	46	512	33	432	22	358

1. Hodonín/Lednice

2. Kostelec/Doksany

3. Mlýny/Chřibská

was a big difference in values of Pearson correlation between the southern and northern part of the Czech Republic, e.g. in silver birch and pedunculate oak.

The best results of a threshold for calculation of growing degree-days (GDD) to beginning of flowering were found in lime tree—the threshold is 5 °C at all three stations. The sums of GDD at the start of beginning of flowering (pre-early spring, early spring, spring and early summer) in the recent years show an increasing tendency, resulting from gradual warming and thus prolongation.

Pearson correlation coefficients between phenophase onset and soil temperature (10 cm depth) are the highest in silver birch, European larch and wood

anemone. Differences in phenophase onset related to average soil temperature are small among particular stations.

All tested inputs could be useful in phenological model, but it is important to test soil temperature also at other depths (e.g. 5, 20 cm, etc.). The results show the need to create more phenological models for different parts of the Czech Republic.

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