Phenological season onsets in the Czech Republic

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Abstract

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Phenological season onsets are defined according to the phenological stages onsets in typical plant species occurring in the Czech Republic. For processing phenological phases were chosen: beginning of flowering 10% of *Corylus avellana* L., *Alnus glutinosa* (L.) Gaert. and *Galanthus nivalis* L. (pre-early spring); beginning of flowering 10% of *Cerasus avium* (L.) Moench, *Betula pendula* Roth. and *Acer platanoides* L. (early spring); fully leaved *Betula pendula* Roth., *Acer platanoides* L. and *Cerasus avium* (L.) Moench. (full spring); beginning of flowering 10% of *Tilia cordata* Mill., *Sambucus nigra* L. and *Dactylis glomerata* L. (early summer); full ripeness of *Sambucus nigra* L. and *Sorbus aucuparia* L. (full summer); leaves colouring 10% of *Betula pendula* L., *Sorbus aucuparia* L. and *Tilia cordata* Mill. (early autumn); leaves fall 100% of *Sambucus nigra* L., *Sorbus aucuparia* L. and *Tilia cordata* Mill. (end of autumn). The season onsets were calculated from 40 phenological stations in the Czech Republic within 1991–2010. Phenological season onsets were executed by GIS methods (Clidata-DEM) into maps. The effect of altitude on the phenological phase onset and duration of selected phenological period (flowering and ripening of black elder) is described in phenotermopluviogram at selected stations (Lednice, 155 m a.s.l.; Měděnec 830 m a.s.l.).

Keywords

phenological phase, phenological season, GIS, phenotermopluviogram

Introduction

Commonly observed phenological events include the timing of sprouting and flowering of plants in the spring, colour changes of plants in the fall, bird migration, insect hatches, and animal hibernation. Because the occurrences of such seasonal phenomena are generally initiated and driven by climate, phenological record is a sensitive proxy for investigating climate change and its influences on ecosystems over time (Hájková et al., 2012). Inevitably, climate and its variability, including the ongoing current changes at various spatial and temporal scales, must impact on agricultural activities. Various indications for shifts in plant and animal phenology resulting from climate change have been observed in Europe. During recent years, phenology, the science of the timing of seasonal plant and animal activity, has had an increasing attention in the context of climate change (Menzel et al., 2001).

The natural seasonality is described with phenological calendars (Schnelle, 1955), which are lists of annual sequence of phenological phases in the form of their starting dates, their duration and the intervals between the phases (Ahas et al., 2000).

The year can be divided into phenological season according to the reaction of nature to the actual course of weather. Phenological seasons are determinated by typical development phases of plants which are in connection with the change in the weather course throughout the year (e.g. bud burst, inflorescence emergence, first leaves, flowering, ripeness, leaves colouring). Similarly, individual season could be described according to the behaviour of animals (e.g. arrival and departure of migratory birds, first flight of bees and occurrence of plant pests).

Phenological maps including the map of the arrival of spring according to Ihne (1885) were stated in the publication "Phenological observation in Moravia and Silesia in the years 1923 and 1924" (Novák and Šimek, 1926). The authors declare: "It is necessary to use different seasons than astronomical or meteorological for knowledge phenological conditions in central European climate. The beginning and duration of phenological seasons significantly differ according to the latitude and elevation. Apart from the 4 basic seasons: spring, summer, autumn and winter, as a rule usually some other adjoining grades are distinguishable, which interpret the relation of the life phases to the atmosphere more exactly." We usually distinguish (according to Ihne, 1885) pre-early spring, spring, summer, autumn and winter (Nekovář and Hájková, 2010; Hájková et al., 2011).

The phenological seasons are defined according to other authors (Kožnarová and Klabzuba, 2004; Petrík et al., 1986) subsequently: phenological pre-early spring is period onset of growing season (e.g. flowering of snowdrop, coltsfoot, snowflake and hepatica), trees and shrubs, e.g. hazel, sallow, cornel, common alder, efflorescent before foliage, and spring works start. Phenological spring is divided into early and full and it corresponds with onset of the main growing season. For phenological early spring is typical when trees (cherry, apple tree, pear-tree) have blooms and leaves at the same time, in full spring full leaved lilac and crane are flowering, and most grass too. Phenological summer classifies into early and full as well, period between summer and autumn is so-called Indian summer. Gradual colouring of leaves and harvest root-crops are characterized for autumn. Defoliation is typical for end of autumn, the main growing season is finishing and winter is coming.

Onsets and durations of phenophase are influenced by weather in each year and weather conditions are expressed usually by daily temperature and precipitation. Other characteristics described air circulation and components of radiation balance are often disregarded even if it is possible to express them by synoptic weather situation.

As explained Eitzinger et al. (2010), there are several seasonal climate variations, such as the El Nino Southern Oscillation or the North Atlantic Oscillation, which are important in determining seasonal weather patterns and can impact on crop yields. Studying how current climatic variability influences crop yields is not only important in providing a baseline for estimation of future impacts, but it can also give insights into potentially useful crop prediction methods. Climate factors represent one of the main inputs for plant growth and have a direct effect on many plant physiological processes such as the onset and duration of phenological stages.

The large-scale circulation of the atmosphere is one of the principal components determining the regional variation in the climate, including wind, temperature and precipitation. The increasing interest in the development synoptic classifications allows interpretation of surface environmental processes and patterns in the synergistic effects of atmospheric characteristics (Bower et al., 2007). Traditional manual subjective methods such as those proposed by Lamb (1950) for British Islands, or Hess and Brezowsky (1977) for Europe, are today replaced by or combined with objective or semi-automated techniques permitting the analysis of large amounts of data using less time and effort (Kožnarová et al., 2009).

The classifications were created for varied purposes, and they differ in the concepts, manifested in the differing spatial and time scale of arrangement of the categories. CHMI (Czech Hydrometeorological Institute) classification, set up for short-term and medium-term regional forecasts, enables to include an integrated circulation process in its categories, which occurs over a large part of Central Europe; it is thus more generous from the systematic point of view, and also uniform for Bohemia and Slovakia (Stehlík, 2002).

The aim of this study was to investigate the annual and spatial variability of the phenological season onset and phenological season duration in the Czech Republic with respect to the weather variability (air temperature and precipitation) between 1991 and 2010.

Material and methods

The CHMI phenological network is consisting of 50 wild plants phenological stations. Voluntary observers monitor the onsets of phenophase following CHMI methodological instructions (Number 2, 3, 10). Patterns of phenophase are in the Phenological atlas (Coufal et al., 2004). The observer carries out observations each lasting two days during the vegetation season, and outside the vegetation period once or twice a week. The vegetation period is defined from March to October. The observed data (expressed in a day of year) are checked and transferred to application Oracle Phenodata (official phenological database of CHMI).

Selected phenological stations with comprehensive database of three plant species were included into the processing. The only exception is obtained phenological stages full onset of summer, which was determined on the basis of a combination of two plant species.

The onsets of individual phenological seasons are defined with some combinations of plants and phenophase. **Pre-early spring** is recommended to be determined according to the beginning of flowering 10%, i.e. according to the appearance of the first blossoms in the following plants: hazel (*Corylus avellana* L.), common alder (*Alnus glutinosa* (L.) Gaert.) and snowdrop (*Galanthus nivalis* L.). For the determining the phenological **early spring**, the phenophase beginning of flowering 10% was chosen in wild cherry (*Cerasus avium* (L.) Moench), silver birch (*Betula pendula* Roth.) and Norwegian maple (*Acer platanoides* L.) – flowers and leaves are developed with a short time lag. For the phenological **full spring** the phenological stage full foliage was chosen. Into the execution were selected silver birch (*Betula pendula* Roth.), Norwegian maple (*Acer platanoides* L.) and wild cherry (*Cerasus avium* (L.) Moench). The period of **early summer** is characterized by flowering of lime tree (*Tilia cordata* Mill.), black elder (*Sambucus nigra* L.) and flowering of grasses e.g. cocks foot (*Dactylis glomerata* L.). The period of phenological **full summer** is typical by ripening of black elder (*Sambucus nigra* L.) and rowan (*Sorbus aucuparia* L.). The phenological **early autumn** is characterized by leaves colouring of silver birch (*Betula pendula* Roth.), rowan (*Sorbus aucuparia* L.) and lime tree (*Tilia cordata* Mill.), the **end of autumn** coincides with leaf fall.

The phenological data of the selected plants were evaluated in the environment of MS Excel, but especially a space analysis in the environment of geographical information systems was carried out. In total, data from 40 stations with MASL (mean above sea level) ranging from 155 m (Doksany, 50° 27' N, 14° 10' E) to 830 m (Měděnec station, 50° 26' N, 13° 08' E) were used for creating the maps. The mean value of three (or two in case of full summer onset) plant species and one phenological stage (e.g. beginning of flowering 10%, fully leaved, full ripeness, leaves fall) were used as an input data into map processing. The data for determination of phenological season were used from the same phenological stations with complete time series. For the depiction of maps, the method Clidata-DEM was used with a horizontal differentiation of 500 m and the distance between two neighbouring phenological stations at similar conditions was 40 km. This method is based on a local linear regression between the measured value (average data of the onsets of the selected phenophase in the period 1991–2010) and a digital model relief. For each station, regressive coefficients from the nearest stations by means of the method of the smallest squares were calculated, which were later consequently interpolated in the space distribution, and by means of map algebra, and a straight line equation, a space distribution of the given phenophase was acquired (Tolasz et al., 2007). The maps are processed from the observed data of the phenological stations; in the area above the boundaries of the present occurrence the map expresses potentially possible values.

From statistical characteristics we chose these parameters: average, median, lower and upper quartile, standard deviation, minimum and maximum.

In case of a lack of climatological stations with phenological observations, therefore were used so-called "technical" series for meteorological elements in this paper. For the data processing ("technical" series), the software packages AnClim (Štěpánek, 2011a), LoadData (Štěpánek, 2011b) and ProClimDB (Štěpánek, 2011c) were created. They offer complex solution, from tools for handling databases, through data quality control to homogenization of time series, as well as time series analyses, extreme value evaluation and model output verification. Thanks to the "technical" series, we have gained a sufficiently large number of climatological series for subsequent analysis, with equal spatial distribution in the territory of the Czech Republic (Štěpánek et al., 2011). The results of the onsets of phenological phases of plant species of the corresponding phenological station in the given year were associated with "technical" series for geographical coordinates of phenological stations in the period 1991–2010 for further processing.

For a detailed analysis of the impact of different weather conditions on phenophase onsets of black elder (*Sambucus nigra* L.) were chosen two phenological stations at different elevations (Lednice 155 m a.s.l., 50° 27' N, 14° 10' E; Měděnec 830 m a.s.l., 50° 26' N, 13° 08' E) in the monitored period. For climatic conditions description was opted modified Walter-Lieth diagram (Fig.1 and Fig. 2), in which we used agrometeorological year with cold half-year (from October to March) and warm half-year (April-September) for the expression. We completed it by more climatological characteristic. Abbreviations used in graph are:

t = average monthly air temperature (°C); r = average monthly total precipitation (mm); t_{year} = average year air temperature (°C); r_{year} = average year total precipitation (mm); $abs\ t_{max}$ = absolute maximum of air temperature; $t_{max\ VII}$ = average monthly maximum of air temperature of the warmest month; $t_{min\ I}$ = average monthly minimum of air temperature of the coldest month; $abs\ t_{min}$ = absolute minimum of air temperature; $t_{min\ XI\text{-}III\ <\ 0.0\ °C}$ = months with average minimum of air temperature <0.0 °C; $abs\ t_{min\ IX\text{-}VI\ <\ 0.0\ °C}$ = months with absolute minimum of air temperature < 0.0 °C; $t_{min\ >\ 0.0\ °C}$ = average count of days with air temperature > 0.0 °C; $abs\ r_{max}$ = absolute maximum of daily total precipitation; $r \geq 0.1\ mm$ = average count of days with total precipitation ≥ 0.1 mm; $r \geq 1.0\ mm$ = average count of days with total precipitation ≥ 1.0 mm; $r \geq 10.0\ mm$ = average count of days with total precipitation ≥ 10.0 mm.

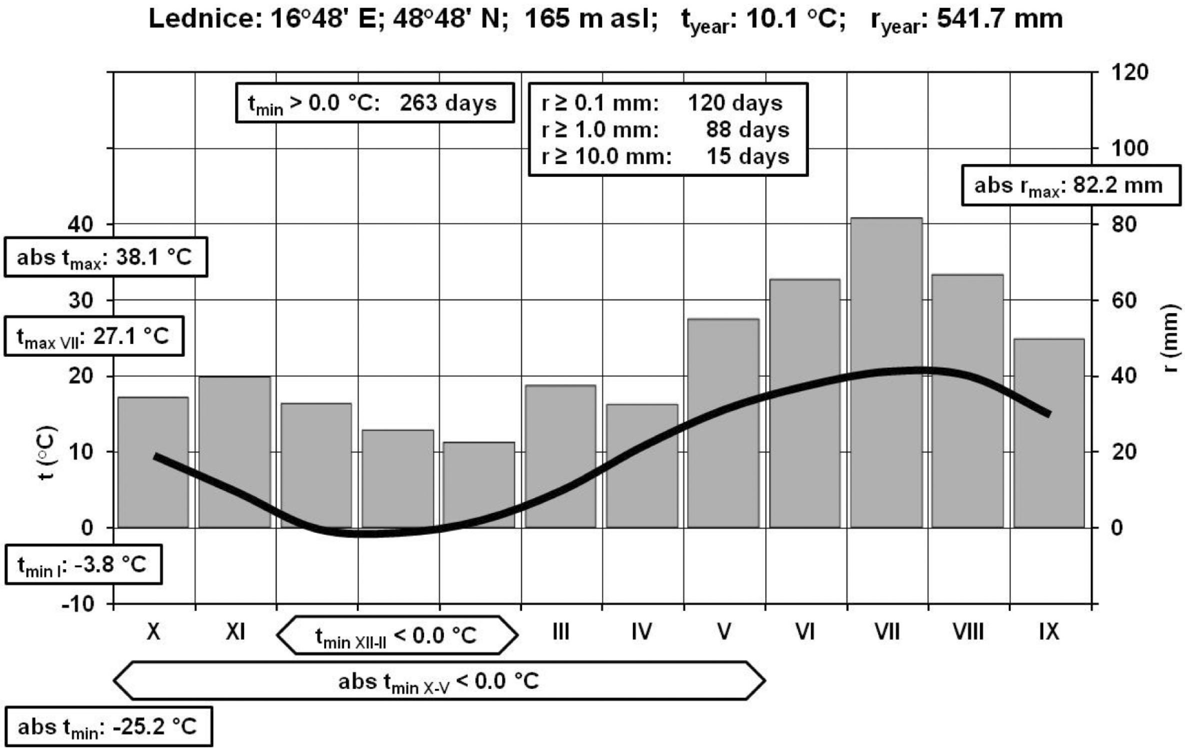

Fig. 1. Climagram of Lednice station.

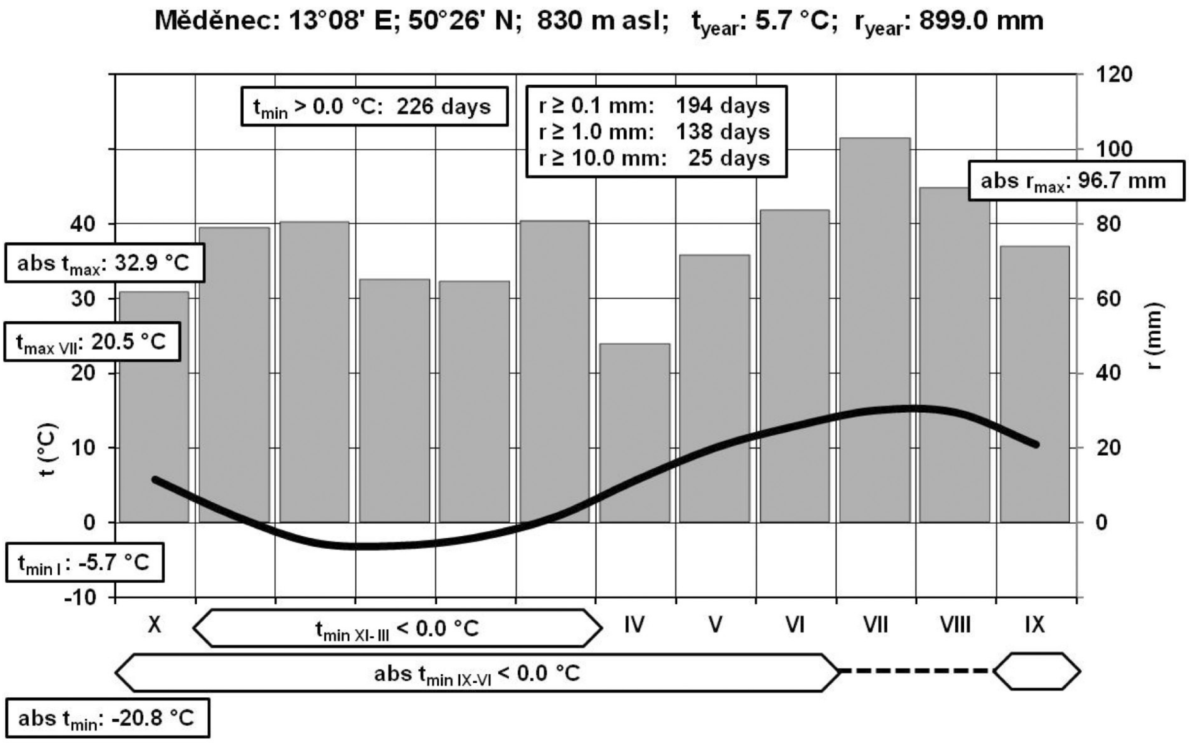

Fig. 2. Climagram of Mědĕnec station.

Relation between temperature and precipitation and length of the flowering and ripening of black elder (*Sambucus nigra* L.) at Lednice and Mědĕnec represents termopluviogram (Kožnarová et al., 1997). It is constructed by average monthly air temperature, average monthly precipitation total and long-term mean of both these characteristics. On axis $\underline{x}$ there is the temperature of total deviation and on axis $\underline{y}$ there is precipitation of total deviation of long-term mean. The long-term mean of both characteristics is placed in the centre of this diagram. Limits of intervals (Table 1) used in the termopluviogram are calculated according to the World Meteorological Organization recommendation (Kožnarová and Klabzuba, 2002).

The termopluviogram was modified and final graph is called "phenotermopluviogram". Sums of temperature and precipitation are calculated from daily values within the period from the beginning of flowering 10% to the full ripeness. Black square is symbol for Lednice station and it is expressed by combination of both of these climatological characteristics (sums of temperature and precipitation). The position of the square in the graph describes condition of temperature and precipitation during the observed period (beginning of flowering–full ripeness) in one year within the interval 1991–2010 (e.g. warm and very wet period). White squares represent Měděnec station.

Results and discussion

Figures 3–10 describe average onsets of phenological phase based on selected species.

Chart (Fig. 3) shows the duration of phenological stages, the vertical phenological gradients are added to the chart. The vertical phenological gradient expresses the time difference of phenological season onset per 100 m elevation; "spring and summer" phenological seasons appear later with increasing elevation, "autumn" phenological seasons occur earlier with increas-

Table 1. Limits of intervals

Temperature Σt [°C]	Precipitation Σr [mm]	Phenological period Σpp [days]	Percentiles [%]
Extraordinary warm	Extraordinary wet	Extraordinary long	<2.0
Very warm	Very wet	Very long	2.0–9.9
Warm	Wet	Long	10.0–24.9
Normal	Normal	Normal	25.0–75.0
Cold	Dry	Short	75.1–90.0
Very cold	Very dry	Very short	90.1–98.0
Extraordinary cold	Extraordinary dry	Extraordinary short	>98.0

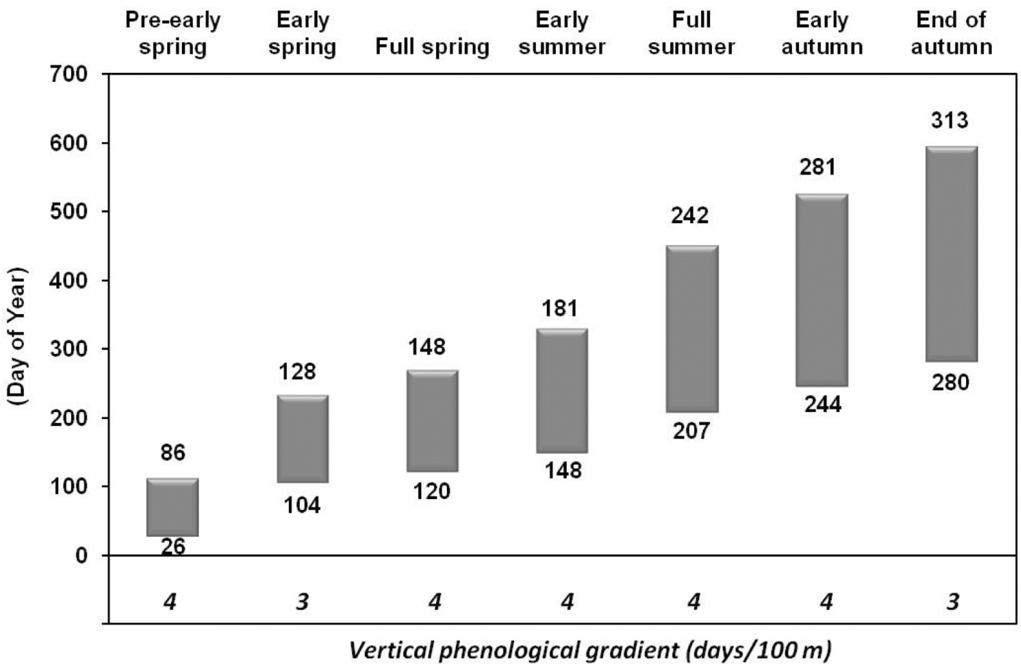

Fig. 3. Extreme data of phenological seasons onsets (day of year).

ing altitude. The vertical phenological gradient shows the shift of onset in dependence on elevation, the number is given in an absolute value.

Pre-early spring (Fig. 4) begins at the earliest before the 1st March (day 60). The latest onset of pre-early spring comes after 17th March (day 76) in the border mountain range. The vertical phenological gradient is 4 days / 100 m.

The German Weather Service (Abb. DWD) issued its phenological calendar in the year 2004 (relative to altitude of 440 m) and divided it into 10 periods. It is based on the observations by the DWD in the period from 1988 to 2002 inclusive (Nekovář et al., 2008). The results of DWD for the pre-early spring onset are between 15th February and 25th March. It begins with the flowering in snowdrop and hazel, continues with the flowering in common alder, coltsfoot, also bud burst in gooseberry.

In the Czech Republic there was the pre-early spring defined as the combination of beginning of flowering 10% in hazel, snowdrop and common alder. The beginning of flowering 10% (median value) in these three species ranges between 5th March (*Galanthus nivalis*) and 19th March (*Alnus glutinosa*) in the Czech Republic.

Early spring (Fig. 5) starts before 19th April (day 109) and the latest onset is in the mountains regions after 5th May (day 125). The vertical phenological gradient is 3 days/100 m. Nekovář et al. (2008) mentioned for Germany (altitude 440 m) the beginning of early spring 25th March and 29th April (it is limited with the flowering in Forsythia and leaves developing in oak and flowering in apple tree). The early spring was used as the beginning of main and large growing season. The mean value for the Czech Republic is 25th April (day 115). As a long-term average (1969–1998) the beginning of growing season (BGS) in Europe starts on 23rd April (Chmielewski and Rötzer, 2002).

The early spring is determined by the beginning of flowering 10% in wild cherry, silver birch and Norwegian maple. The beginning of flowering 10% (median value) in these three species ranges between 22nd April (*Betula pendula*) and 14th May (*Cerasus avium*). According to Novák and Šimek (1926) the onset of spring in Moravia and Silesia was between 21st April (111 day) and 20th May (140 day) in the year 1923.

Full spring (Fig. 6) begins at the earliest in the lowlands before 4th May (day 124) and in the highest elevations after 20th May (day 140). The phenological gradient is 4 days / 100 m.

DWD evaluated for the elevation of 440 m the onset of full spring between 29th April and 29th May – flowering in apple tree and black elder (Nekovář et al., 2008). In the Czech Republic there was used for the determination full foliage in silver birch, Norwegian maple and wild cherry. The fully leaved onset (median value) in these three species oscillates between 8th May and 15th May.

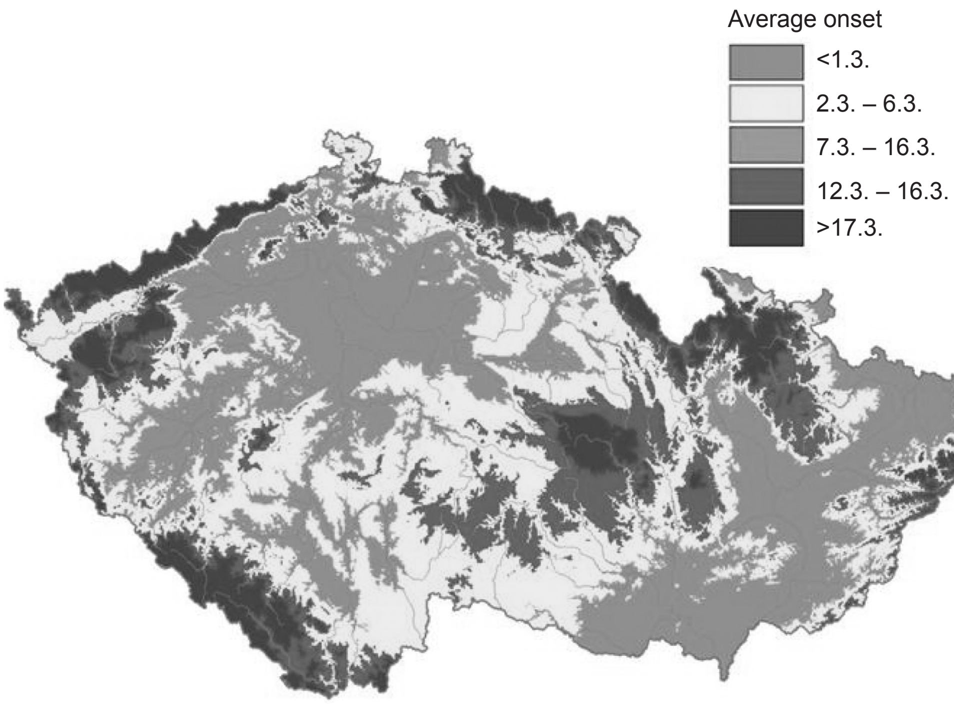

Fig. 4. Average onset of pre-early spring.

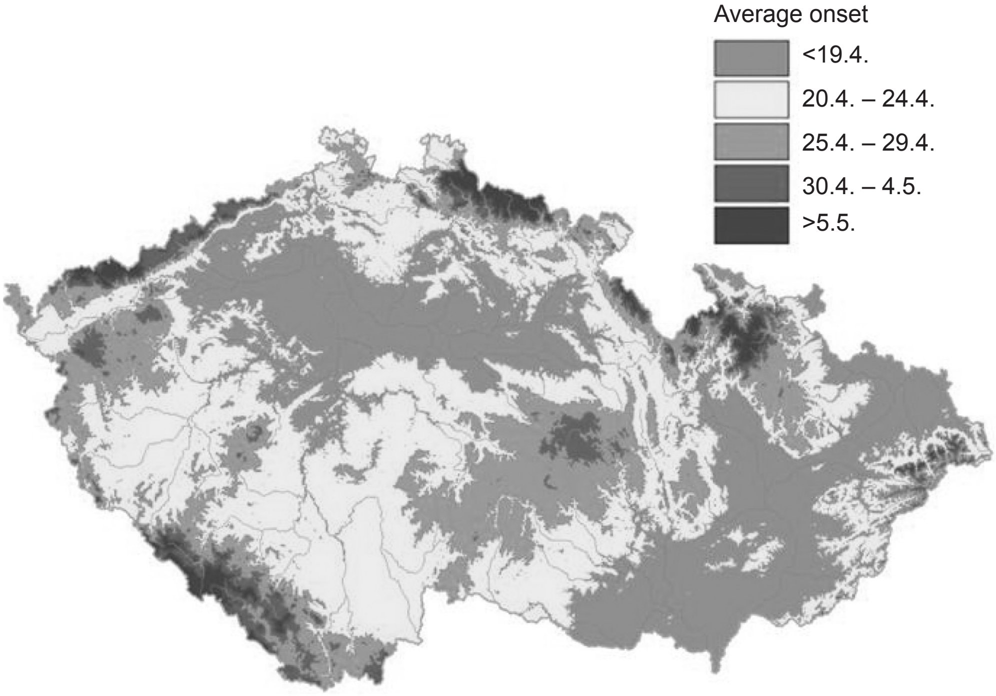

Fig. 5. Average onset of early spring.

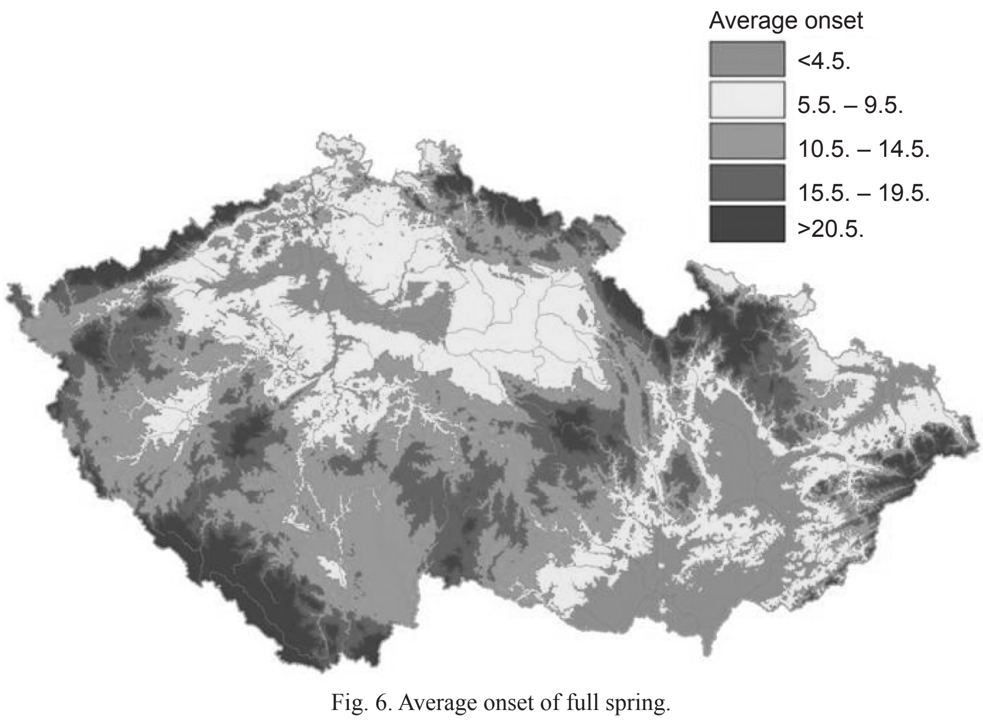

Fig. 6. Average onset of full spring.

Early summer (Fig. 7) comes at the earliest before 3rd June (day 154) the latest onset is e.g. in the highest mountain elevations (after 24th June – day 175). The vertical phenological gradient is 4 days/100 m.

According to the DWD results the early summer revealed between 29th May and 21st June (black elder and lime tree flowering, ripening of red currant). We have used for determination of early summer beginning of flowering 10% in lime tree, black elder and cocks foot, the median value of these three species is between 25th May (*Dactylis glomerata*) and 26th June (*Tilia cordata*).

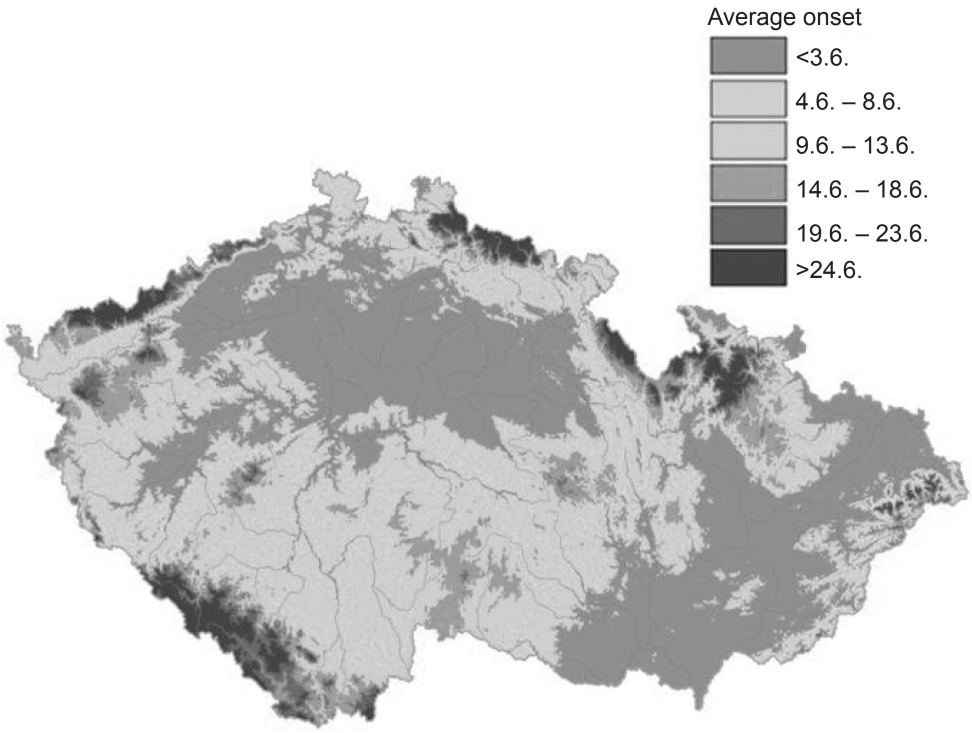

Fig. 7. Average onset of early summer.

Full summer (Fig. 8) begins firstly in lowlands and in the lower catchment of the Ohře and Dyje river (before 28th July – day 209), the latest onset of full summer comes after 18th August (day 230).

DWD results show the occurrence of full summer between 21st June and 5th August (vine blossoms, gooseberry, late cherries, early plums ripen). Full summer was determinated in our study by fully ripeness of

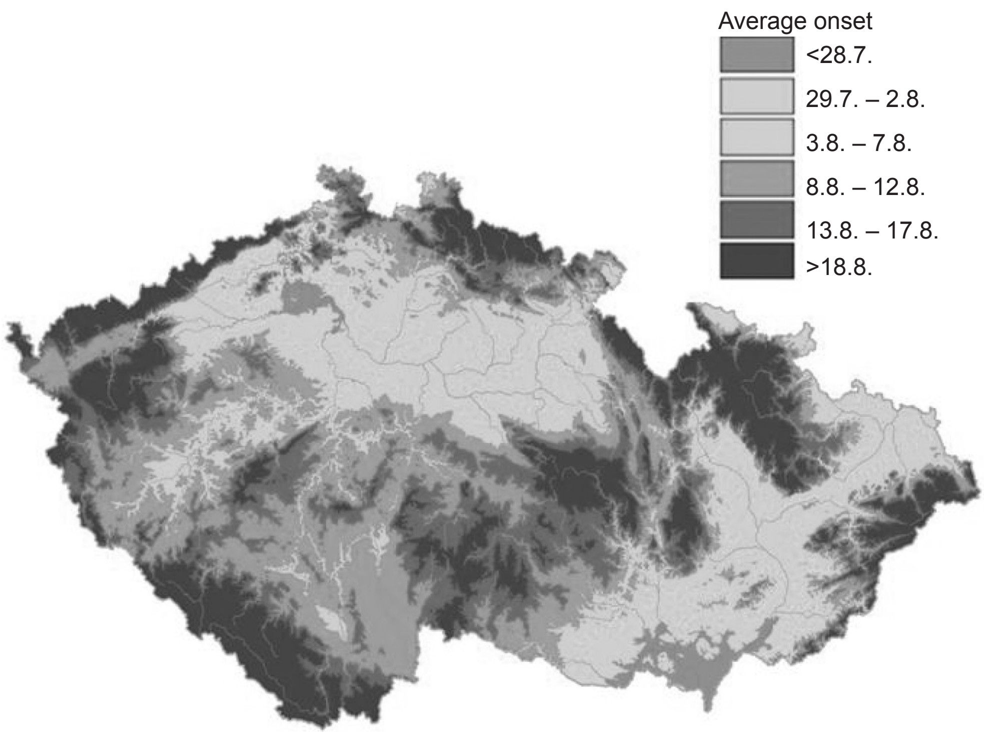

Fig. 8. Average onset of full summer.

black elder and rowan; the median values are 7th August (*Sorbus aucuparia*) and 21st August (*Sambucus nigra*).

Early autumn (Fig. 9) starts at the earliest at mountain elevations usually before 16th September (day 259) and the latest onset is later than 2nd October (day 275). The vertical phenological gradient is 4 days / 100 m.

DWD results of early autumn vary between 28th August and 22nd September (dogwood, wild rose, chestnut, oak ripen). Early autumn in the Czech Republic has been set by leaves colouring 10% in silver birch, rowan and lime tree. Median values of these three species are between 17th September (*Sorbus aucuparia*) and 28th September (*Tilia cordata*).

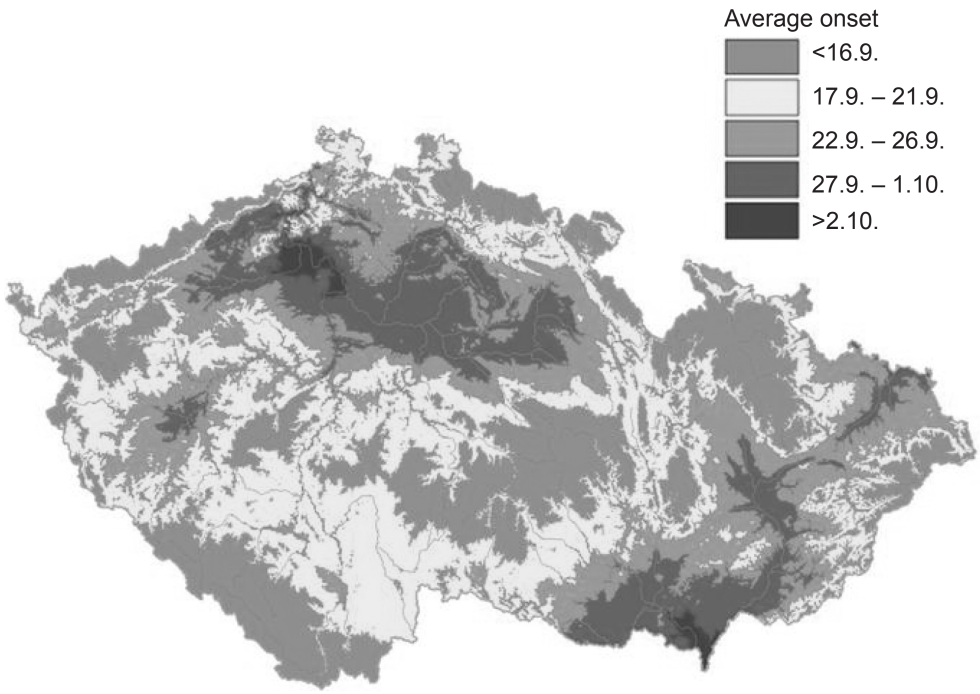

Fig. 9. Average onset of early autumn.

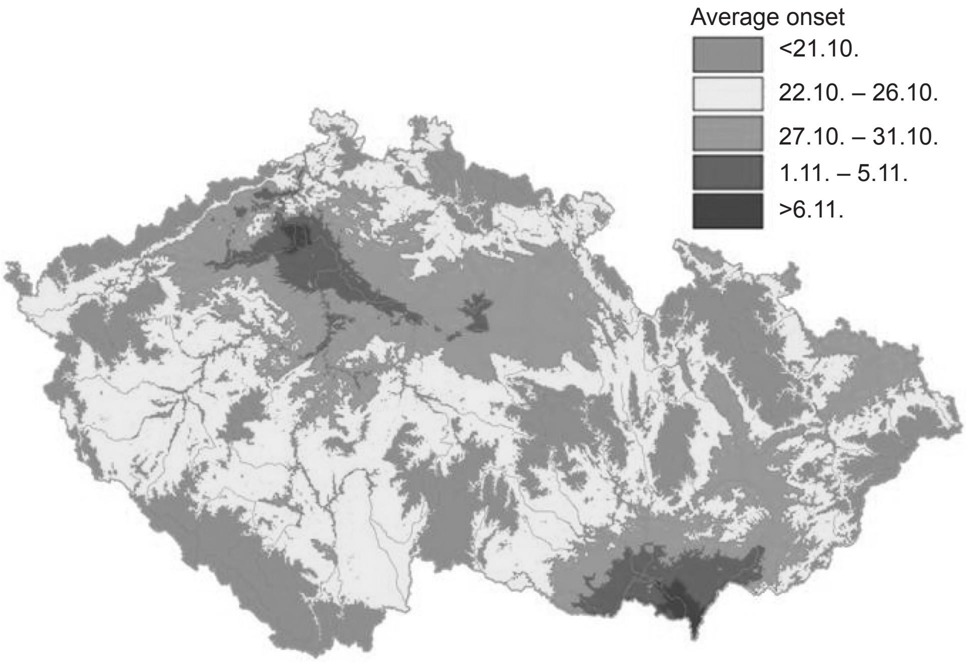

Fig. 10. Average onset of end of autumn.

End of autumn (Fig. 10.) begins in the middle and higher elevations before 21st October (day 294) and the latest onset occurs after 6th November (day 310). The vertical phenological gradient is 3 days/100 m.

The end of autumn of DWD results begins after 15th October. The phenological stage leaf fall indicates the end of autumn in the Czech Republic. The results (median value) of black elder, rowan and lime tree are between 23rd October (*Sorbus aucuparia*) and 30th October (*Tilia cordata*).

Detailed statistical characteristics of phenological season's onsets (average, median, lower and upper

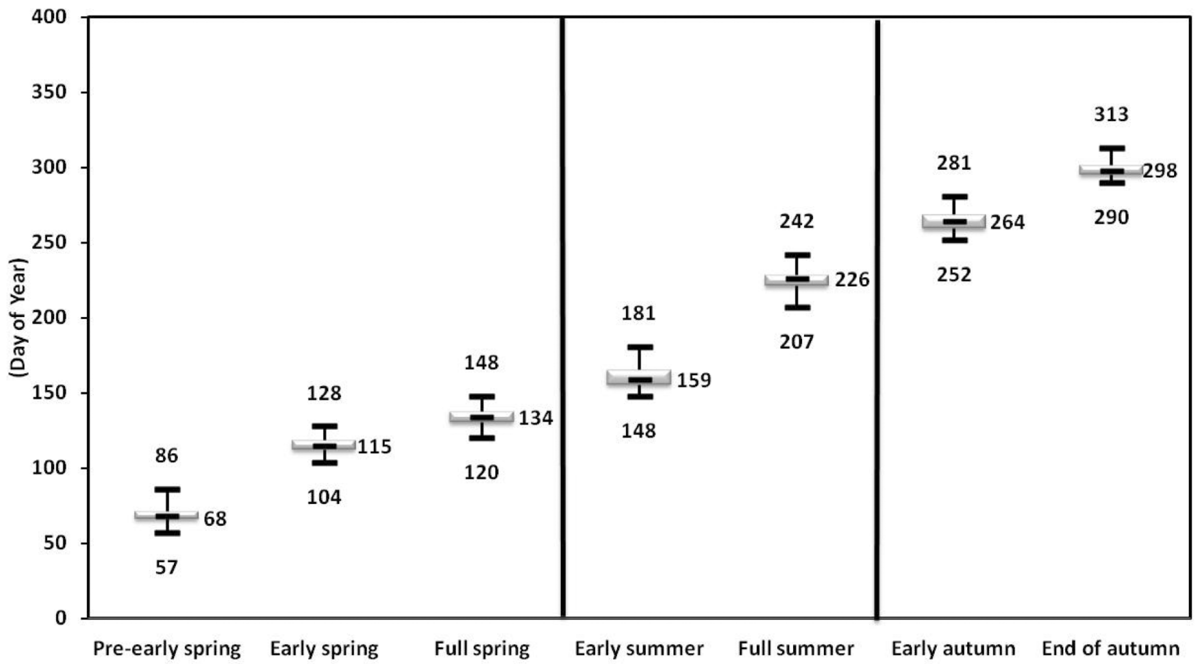

Fig. 11. Box plots of phenological seasons of year.

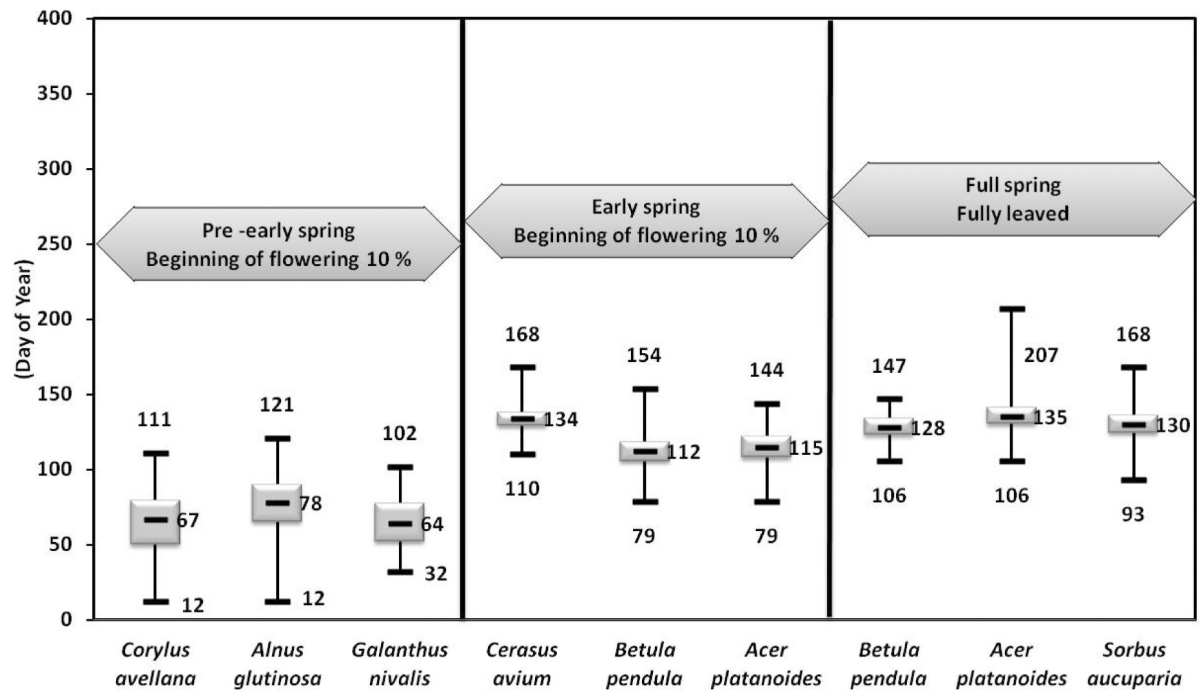

Fig. 12. Box plots of spring phenological onsets.

quartile, standard deviation, minimum and maximum) of pre-early spring, early spring, full summer and end of autumn are presented in Figs 11, 12, 13 and 14. The standard deviation of these phenological seasons ranges between 5.4 (early spring) and 8.9 (full summer), the difference between average and median is 1 day.

The duration of phenological seasons is different during the year. The early spring has the shortest duration (19 days on average); on the contrary the early summer shows the longest duration (65 days on average). Pre-early spring takes 46 days on average, full spring lasts 27 days on average, full summer lasts 39

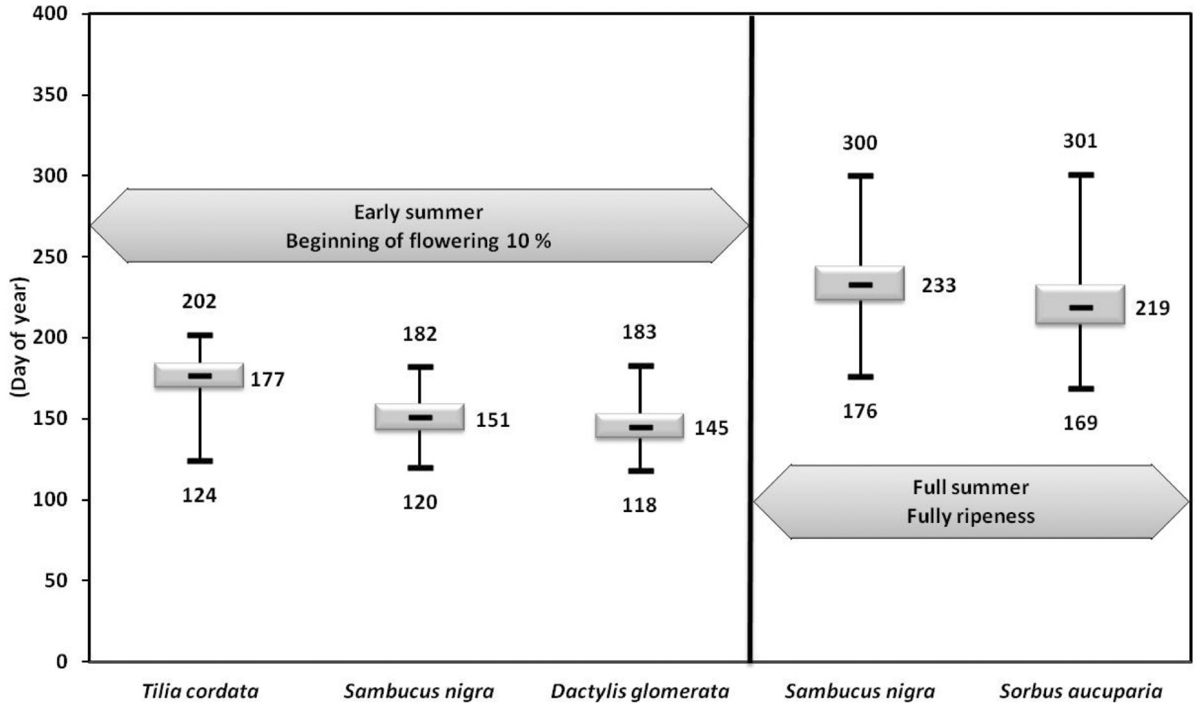

Fig. 13. Box plots of summer phenological onsets.

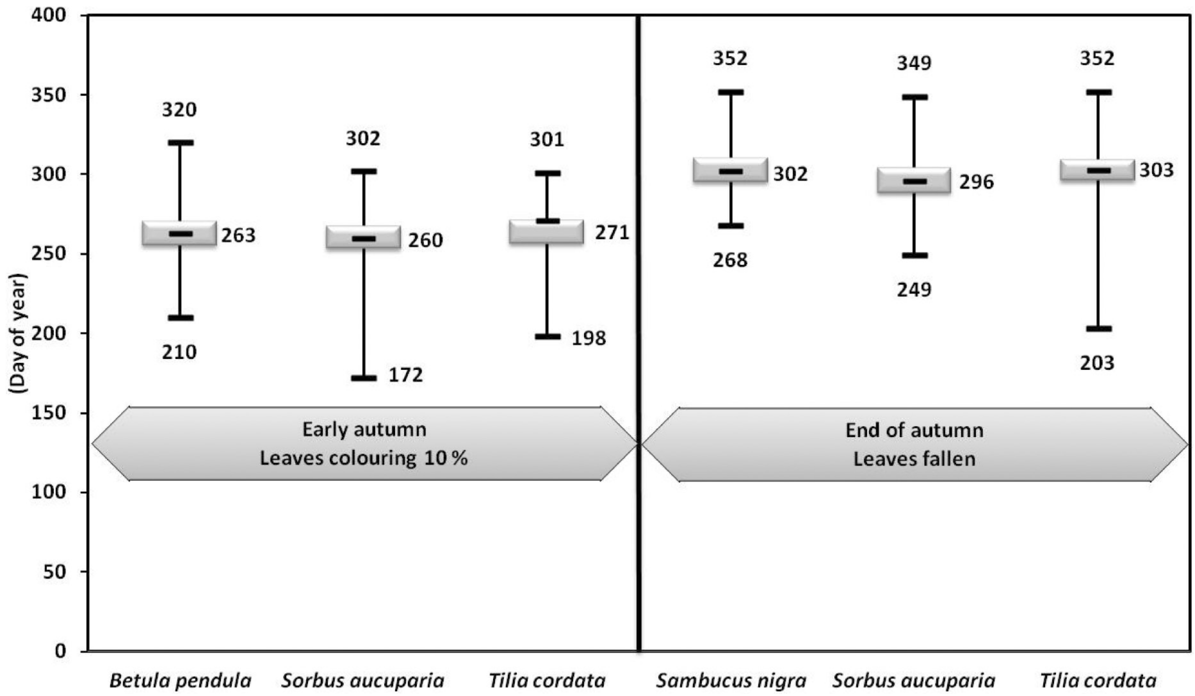

Fig. 14. Box plots of autumn phenological onsets.

days on average and early autumn takes 35 days on average. The main growing period lasts on average 149 days (early spring-early autumn) and the large growing period takes 184 days on average (early spring-end of autumn).

The duration of period from beginning of flowering to ripeness of black elder (*Sambucus nigra* L.) at stations in Lednice (155 m a.s.l.) and Mědĕnec (830 m a.s.l.) is described in Table 2. Table 2 presents years with the longest and the shortest duration of phenological phases of black elder.

The phenotermopluviogram on Fig. 15 represents relations between air temperature and precipitation totals in interval of beginning of flowering 10% to full ripeness at location in Lednice and Mědĕnec.

Long-term mean in the centre of graph (gray point) for Lednice station is ∑t = 1,470.3 °C (air temperature); ∑r = 171.4 mm (precipitation) and duration of flowering and ripening = 75 days. Long-term mean in the centre of graph (the same gray point) for Mědĕnec station is ∑t = 1,134.5 °C; ∑r = 224.1 mm and duration of phenophases = 76 days.

The period is shorter in colder and drier years; on the contrary this period is much longer in warmer years with higher amounts of precipitation. These years are expressed in the graph.

The longest period of flowering and ripening at location in Lednice was 89 days (1992), with the sum of air temperature (∑t) 1,838.5 °C and the precipitation total (∑r) 141.2 mm; at Mědĕnec location 103 days (2000), ∑t = 1,402.1 °C and ∑r = 237.8 mm. The shortest interval was at location in Lednice 62 days (1993); ∑t = 1,158.8 °C and ∑r = 173.6 mm, and at Mědĕnec station 47 days (2004), ∑t = 747.8 °C and ∑r = 161.6 mm.

Table 2. The longest and the shortest duration of flowering and ripening of black elder

Station	Flowering		Ripeness		Beginning of flowering – full ripeness	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Lednice (165 m a.s.l.)	Year: 2007 47 days	Year: 2006 21 days	Year: 2009 66 days	Years: 1994, 2007 41 days	Year: 1992 89 days	Year: 1993 62 days
Mědĕnec (830 m a.s.l.)	Year: 2001 48 days	Year: 2008 16 days	Year: 2000 79 days	Year: 2001 19 days	Year: 2000 103 days	Year: 2004 47 days

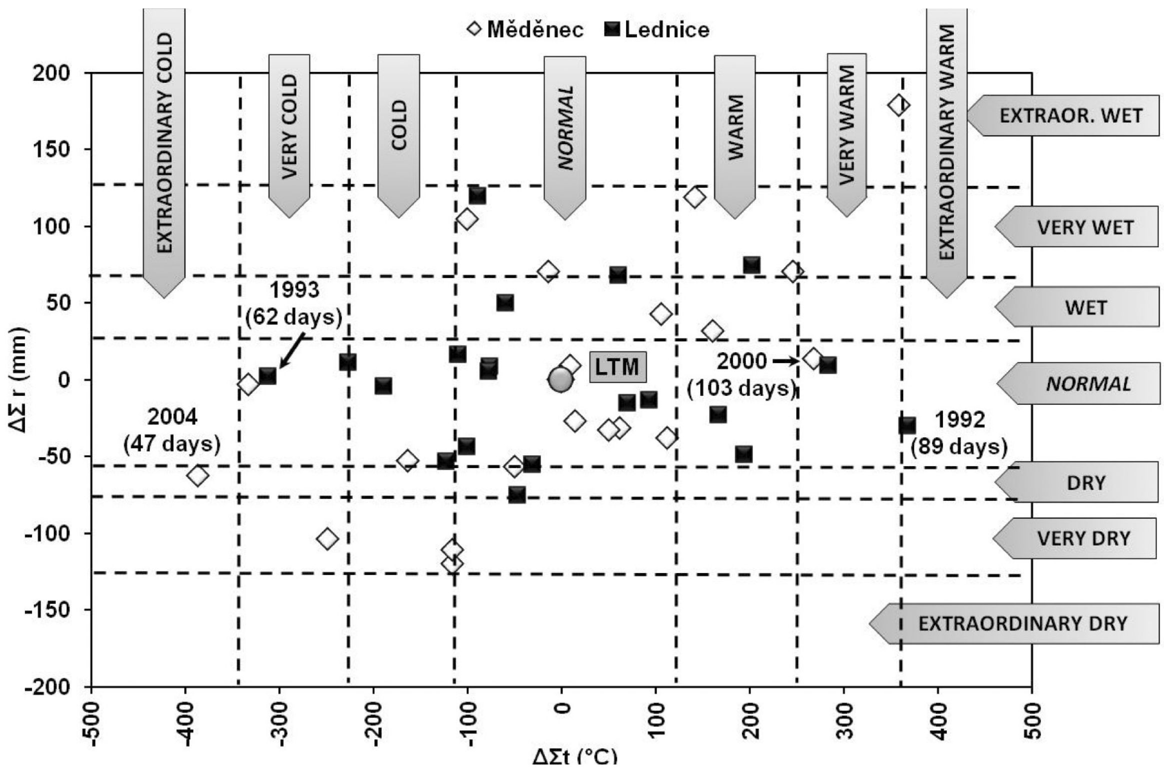

Fig. 15. Phenotermopluviogram.

Conclusion

It is very difficult to objectively compare phenological stages onsets at different regions and in various periods. Phenological data always show temporal variations of plant development and express the biological limits and their dependence on climate and weather. A significant role is also played by observation and evaluation methodology. There were several fundamental changes in the methodology of phenological observations in the Czech Republic in the recent years. Single procedure used in plant material, building of station network under the auspices of the Czech Hydrometeorological Institute, a new methodology of observation and assessment has begun in 1991 and analysed dataset has a relative short time period (1991–2010).

From our analysis and map processing phenological seasons are as follows: the average onsets of phenological seasons in the selected elevation zones in the Czech Republic are: pre-early spring (1st March–26th March, vertical phenological gradient: 4 days / 100 m), early spring (16th April–7th May, vertical phenological gradient: 3 days / 100 m), full spring (3rd May–26th May, vertical phenological gradient: 4 days / 100 m), early summer (29th May–30th June, vertical phenological gradient: 4 days / 100 m), full summer (29th July–30th August, vertical phenological gradient: 4 days / 100 m), early autumn (4th September–3rd October, vertical phenological gradient: 4 days / 100 m) and end of autumn (14th October–4th November, vertical phenological gradient: 3 days / 100 m).

From the pre-early spring to the early spring elapse 46 days, from the early spring to the full summer 110 days and from the full summer to the end of autumn 74 days on average. If we define the growing period from the early spring to the end of autumn (it approximately corresponds with the main growing season), it lasts 184 days on average. Menzel et al. (2001) have revealed a lengthening of the growing period (the growing period in 1974–1996 was up to 5 days longer than in the 1951–1973 period). Scheifinger et al. (2002) have also found the vegetation period of many plant species has been increased through an advanced onset of spring phases and a forward shift of autumn phases in mid latitudes.

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