The limits of the vegetative period, defined based on daily mean temperature: a comparison of various approaches

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Abstract

Hora, P., Štěpánek, P. 2011. The limits of the vegetative period, defined based on daily mean temperature: a comparison of various approaches. *Folia oecol.*, 38: 28–37.

The vegetative period can be defined by using daily mean temperature values. In Czech and Slovak climatological praxis, temperatures of 5 °C, 10 °C and 15 °C are used to limit different parts of the vegetative period. This article analyses and compares two basic methods for the estimation of the beginning and end date of the vegetative period: a method of consecutive days and a method operating with temperature sums. The first method works only with the number of days with a temperature above the given limit; the second examines the particular temperature values. These two methods (or three – because the first method has two variants, 6 or 5 consecutive days) were tested on a so-called technical series for 268 climatological stations of the Czech Republic and assembled during the period of 1961–2007. Also, long-term averages instead of data from particular years were utilized for analysation. ProClimDB software, which is also available in a freeware version, has been developed for all the calculations.

Key words

air temperature, period with prevailing temperatures, phenology, vegetative period

Introduction

The vegetative period is a basic concept used in many research fields, such as ecology, agriculture, climatology, etc. Sobíšek (1993) defines it very simply as the period in which plants have optimal conditions for growth. In this context, air temperature and precipitation are the most important climatological variables. Because each plant has its own ecological demands, the vegetative period varies among individual species. The best estimation of the vegetative period is done by observing specific plants in nature. This subject of study is the research field referred to as phenology. It deals not only with the course of significant periodical repetitive life activity of plants and animals, but also investigates their dependence on manifestations such as environmental conditions, especially weather and climate (Sobíšek, 1993). The practical output of this research field, in both the Czech Republic and Slovakia, was a simplified definition of the vegetative period, based on air temperature. From this, the Czech and Slovak climatological praxis applies the terms "great vegetative period", limited by reaching and then dropping to a daily mean temperature of 5 °C and "small (main) vegetative period", limited by reaching and then dropping to 10 °C. "Vegetative summer" is another term that is used which refers to the start and end dates of daily mean temperatures of 15 °C. It should be noted here that researchers often avoid using the abovementioned terms and, e.g. the great vegetative period limited by the dates mentioned above is called the period with prevailing temperatures above 5 °C. The given definitions of the vegetative period (also applied in this general context on vegetative summer) are quite clear, but the problem is applying them in practice. Daily mean temperatures rarely continuously increase in spring and decrease in autumn. The more frequent case is that air temperature reaches the limit given in the definition of the vegetative period for one day, but again drops below this limit in subsequent days. The limit may only be permanently exceeded (in the part of the year when temperatures generally rise) a very long time after the first occurrence in the year.

In the past, the delimitations of the abovementioned characteristic periods were carried out by means of dates of monthly mean air temperatures (Vesecký, 1961). Values were taken at the middle of a month (15th day). For the calculation, between these dates, air temperature constantly rose or fell. In this way, the annual course of air temperature was smoothed and, except in certain cases (e.g. mean monthly temperature of above 5 °C in March and below 5 °C in April), the estimation of the beginning and end date was not at all complicated. The estimation during the warmest or coldest months of a year is more problematic. When the values are assigned to the 15th day of the month, it results in the temperatures of the other days of the warmest months being underestimated and the temperatures of the other days of the coldest months being overestimated. This discrepancy leads to systematic errors in setting limits for the vegetative period. The general problem in using the monthly mean temperatures is overly-strong simplification that may result in establishing the start of the vegetative period on a day in which the air temperature was lower (or higher) than the limit required by the definition.

In literature, we often see the results of statistical processing being given without the proper description of (or reference to) the methodology. The evaluation of periods with prevailing temperatures in *Agroklimatické podmienky ČSSR* (Kurpelová et al., 1975) is an example of this.

The development of computing technologies in recent years has enabled the application of more complicated methods that work straight with daily values for identifying the limits of the vegetative period.

Material and methods

In this work, we analyse and compare two basic methods that work with daily mean temperatures to estimate the beginning and end date of the vegetative period in individual years. As mentioned above, such methods (working with daily data) could only be widely applied in recent years with the development of computers. Thanks to fast computers, it is possible to invent very sophisticated methods that fit well with processes taking place in nature. This works only as long as the vegetative period (i.e. the period in which vegetation develops) is set based on the limit value of air temperature.

We will discuss two methods in this work, one of which has two versions (modifications), so three final results will be given.

We will call the first method the method of consecutive days. This method was used e.g. in the CECILIA research project (EC 6th Framework Programme) (Pokladníková et al., 2008). The beginning of the period commences with the first interval of at least 6 days with a daily mean temperature above the defined level. The end of the period comes with the first interval of 6 days with a daily mean temperature below the defined level. The important rule is that the beginning of the period must be in the first half of the year and the end of the period in the second half of the year. This method can be easily applied on computers but it does have some problems. In the case of a warm weather episode, the beginning of the period can occur in the early days of year (February, March), only to be followed by a drop in temperatures to low values that can last for a very long time. In praxis, this problem can be reduced if the first two months of the year are omitted from processing (the beginning of the period can start in March, at the earliest). However, this approach is rather controversial because an earlier start of the vegetative period in some years and locations cannot be considered wrong. The early end of the period in cases when temperatures temporarily drop below the limit is a similar problem. In the CECILIA project, this methodology was used only for delimitation of the great vegetative period. Pokladníková et al. (2008) uses this method for determining the limits of the small vegetative period, as well. The condition of 6 consecutive days, however, seems too strong. While air temperatures around 5 °C usually occur in the parts of the year with steep temperature gradients (in the annual cycle), temperatures of 10 °C for stations with higher elevations or 15 °C generally occur in areas without such distinct gradients. For these higher limits, air temperature usually fluctuates, thereby decreasing the frequency of occurrences above the limit value. The length of the small vegetative period and vegetative summer is shorter than the great vegetative period. This fact might suggest delimiting the beginning and end of the vegetative period by only using 5 or even less consecutive days. Another problem is dating of the beginning till the end of June and the end after the beginning of July. This does not influence limits for periods with 5 °C and more, but in the case of 10 °C for stations with higher elevations and for 15 °C in general, it may not be until July that the first occurrence of 6 consecutive days occurs. In this work, it has not been our intention to shift the "middle of the year", but, alongside 6 consecutive days, we also investigated how the results would change if only 5 consecutive days were applied (this is the second variation of the first method).

The second method discussed in this article was used e.g. in the *Climate atlas of Czechia* (Tolasz, 2007). This method, referred to as the "sums of temperatures method" is more sophisticated than the previous one. It not only uses the days with the given temperatures, but also particular values of the temperature. The first step is the calculation of the temperature sums in the warm and cold periods (the periods with temperatures above or below the given value). The beginning of the vegetative period is decided based on the fact that the sum of temperature differences from a given limit during cold waves is smaller than the sum calculated during warm waves from the beginning of the period. The end of the period is also estimated in a similar manner (when the sum of temperature differences from a given limit during cold waves prevails over those of warm waves). With this method, it is possible for the beginning of the period to be determined by an interval of just one day with temperature above a particular level.

Those two methods (or three – because of the two variants of the first method) were tested on a so-called technical series for 268 climatological stations in the Czech Republic in the period of 1961–2007. By a technical series, we mean a quality-controlled homogenized series with filled gaps. Details about the technical series can be found in Štěpánek et al. (2011), quality control and homogenization is described e.g. in Štěpánek et al. (2009).

The last point will discuss the long-term average of daily mean temperature as a means for simpler definition of the average beginning and end date of the vegetative period at individual stations.

This work extends the findings from previous work dealing the issue through data gained from a smaller sample of stations (Hora, 2009).

Results

Period with prevailing temperatures above 5 °C – beginning date

The sums of temperatures method (hereinafter referred to as TS) and the method of 6 consecutive days (CD6) give the same results (beginning date) in 49% of cases. This number is valid for all the stations in the Czech Republic; for individual areas, the same results varied from 30 to 72% within the period studied, 1961–2007. For all the stations, in 29% of cases, an earlier beginning date was estimated with the method of temperature sums as compared to the method of 6 consecutive days, a later date was estimated in the remaining 22%. The largest absolute difference between these two methods was 95 days (method TS delayed after method CD6), as opposed to, TS outrunning CD6 by 53 days, at the most. The mean absolute difference was 11 days.

Differences between the CD6 and CD5 (5 consecutive days) methods are driven by certain rules. First, CD6 cannot estimate the beginning date earlier than CD5. Second, in there were more cases with CD6 in which vegetative periods were not identified due to 6 consecutive days with the temperature above the given limit not occurring in the particular year. Nonetheless, this rule was manifested mainly for defining limits of the period with prevailing temperatures of 10 and 15 °C; in the case of the great vegetative period, this has never happened. The same results for CD6 and CD5 were obtained in 78% of the cases for 5 °C. For individual stations, it varied from 57 to 94% of cases. For all stations, CD6 have results delayed compared to CD5 in 22% of cases. The maximum difference between the two methods was 106 days; the mean absolute difference was 5 days.

Because of the difference between CD6 and CD5, comparison results of TS with CD5 are not the same as TS with CD6. CD5 method coincides with the TS method in 48% of cases (for all stations); it varies from 19 to 66% for individual stations. The TS method shows earlier results compared to CD5 in 19% of cases, while delayed results in 33% of cases. The maximal differences between TS and CD5 are the same as for the TS and CD6 comparison: 95 days for later date applying TS and 53 days for earlier date applying TS. The mean absolute difference was 11 days.

Figure 1 shows different results for the individual methods on concrete dates, in this case, for the station Protivanov in the year 2007. The graph shows the values of the daily mean temperature from the 60th day of the year (1st March) till the 109th day (19th April). Bars relative to 5 °C are used to simplify the explanation (warmer or colder days are easily identified). The first three consecutive days in the year with an air temperature of 5 °C or more had already been recorded on 9th January. 5 consecutive days were recorded on 12th March (CD5 method). The first 6 consecutive days were recorded on 9th April (CD6). The method of temperature sums (TS) estimated the beginning of the period in a different way, as 25th March. This method, as explained above, works with temperature values of individual days and compares cold and warm waves (with regard to a limit value). In the case we are using for illustrative purposes, the 25th of March to 8th of April is an important period. Since the sum of positive deviations from the limit value of 5 °C is higher than the sum of negative deviations from the same limit (i.e. average temperature for the given period is equal or higher than 5 °C), this period is regarded as part of the vegetation period. Warm waves also occurred before the 25th March, but those warm waves were followed by "stronger" cold waves.

In previous paragraphs, we described the frequencies and the sizes of differences for individual methods and for individual years. For the average beginning dates of the great vegetative period (in the period 1961–2007), the differences are smaller. Differences for average beginning dates, a limit temperature of 5 °C, individual stations and the TS and CD6 methods are shown in Fig. 2. The maximal difference is 17 days delay, or 2 days earlier beginning date for TS compared to CD6 method. Figure 2 and those that follow depict values according to the altitude of a station in order to determine whether we can speak about results being dependent on altitude. For the limit value of 5 °C, such dependence is not evident. The average difference of the beginning

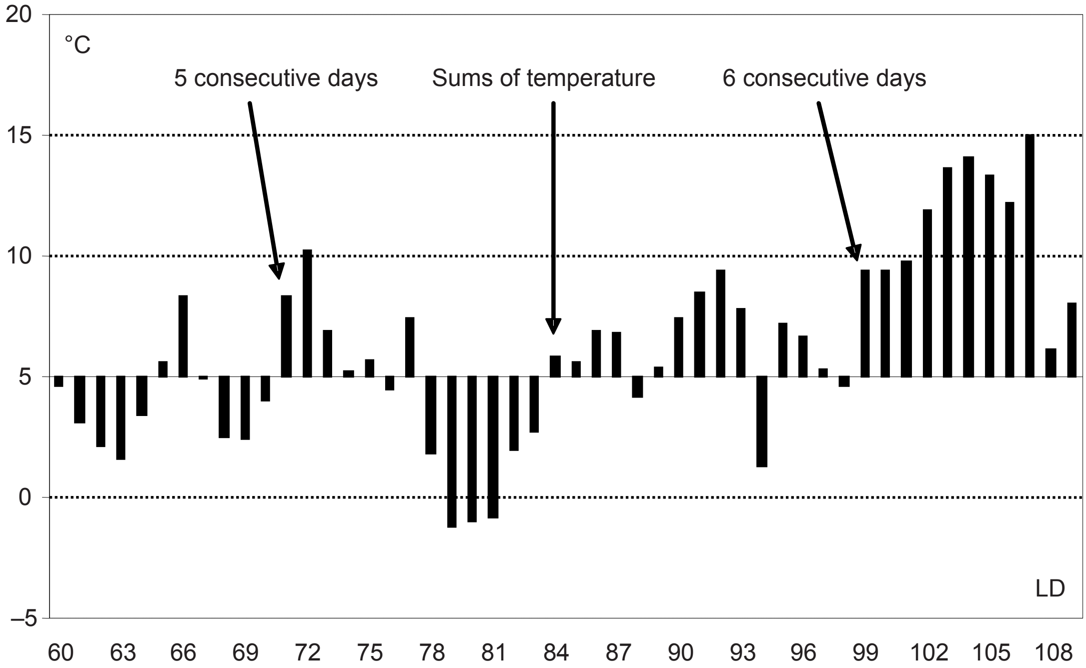

Fig. 1. Daily mean temperature in Protivanov in 2007 from March 1St to April 19th with marked delimitation of beginning date applying various methods.

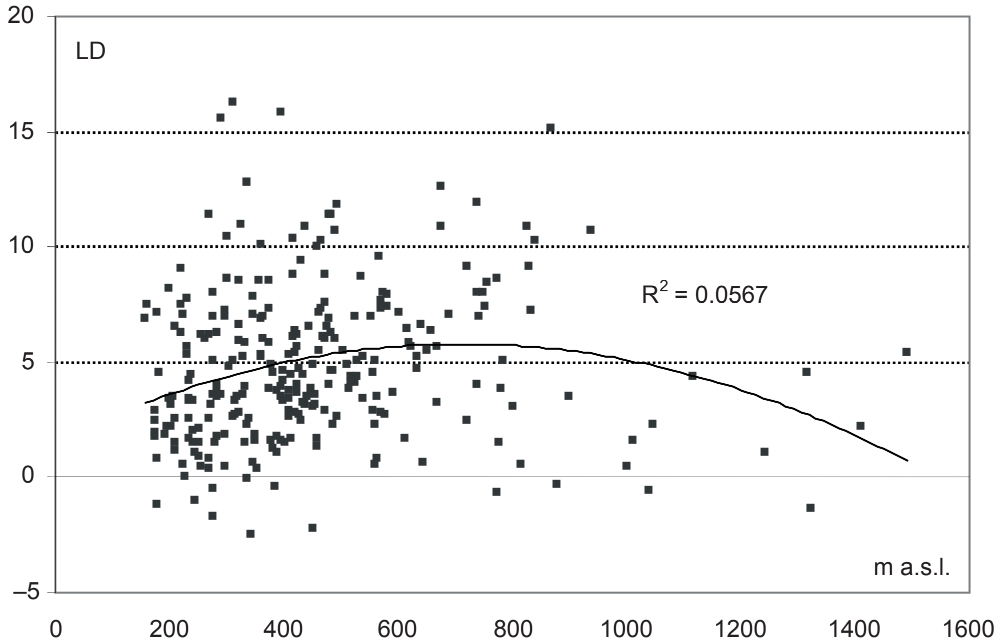

Fig. 2. Beginning of the period with prevailing temperatures 5 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

date between TS and CD6 method for all stations was a 5-day delay of TS method. Compared to CD6, the CD5 method gives an earlier beginning date as well, by 5 days, but for individual station it varies from 1 to 12 days. The TS method, when compared to CD5, results in all stations having an average delay of 10 days.

Period with prevailing temperatures above 5 °C – end date

The results of the TS and CD6 method coincide in the end date timing for 5 °C in 50% of cases; from 28 to 72% for individual stations. In 38% of cases, earlier date of end is given by TS method, in 12% cases by CD6 method. The largest absolute difference between the two methods was 103 days of delay of TS after CD6 method; on the contrary, an earlier end date using TS, as opposed to the CD6 method, was at most, 54 days. The mean absolute difference was 6 days.

The results of the CD6 and CD5 methods coincide in 83% of cases. The rest (17%) belong to later end of period in CD6. For individual stations, the same results agree in 72 to 96% of cases. The maximal difference is 108 days – delay of CD6 method after CD5, the mean absolute difference is 3 days.

The TS method coincides with CD5 in 51% of cases; from 34 to 68% of cases for individual stations. In 29% of cases earlier end date is given by TS method, while in 20% of cases by CD5 method. The maximal difference between the methods was 108 days of delay and a 40-day earlier end date with TS. The mean absolute difference was 7 days.

For average end dates of the great vegetative period (in the period 1961–2007), the differences in the results when using the various methods are smaller than in the case with the beginning date. The differences in results for TS and CD6 are shown in Fig. 3. With this, we can start to consider that the results do depend on the altitude. For stations with lower altitudes, the TS and CD6 methods give a difference of 4 days (both earlier and delayed date) for individual stations. For stations with higher altitudes, the end date estimated by TS is later than that given with using the CD6 method, by a maximum of 11 days. In an average of all stations, the difference between the two methods is zero. The CD6 method is delayed after CD5 for individual stations from 1 to 9 days; by 3 days in an average of all stations. Then in an average of all stations, the TS method is delayed by 3 days when compared to CD5.

Length and other characteristics of period with prevailing temperatures above 5 °C

The various beginning and end dates given by the methods is reflected in the various lengths of vegetative periods. In an average of all stations, the great vegetative period given by the TS method is shorter by 5 days compared to those given when using the CD6 method and by 7 days compared to those given when using CD5. For individual stations large variability is seen in the results for individual stations: in stations with lower altitudes, a shorter period is prevalent when the TS method is employed, by up to 18 days. For colder stations, this difference changes, and in an extreme example, the length of the vegetative period estimated by TS was longer by 8 days compared to CD6.

We showed earlier that different methods often give different results. In regard to average results for the period 1961–2007, discrepancies are somewhat suppressed. This was valid for the delimitation of the beginning and end date of the vegetative period. The question is whether it is also valid for other characteristics, like the sum of temperatures over a period, precipitation total, etc. We will not be discussing such characteristics in this article but we do need to make a few comments related to this. The influence of the period length on some of the characteristics is straightforward: a longer period given by one of the methods also means that the sums of temperature or precipitation sums will

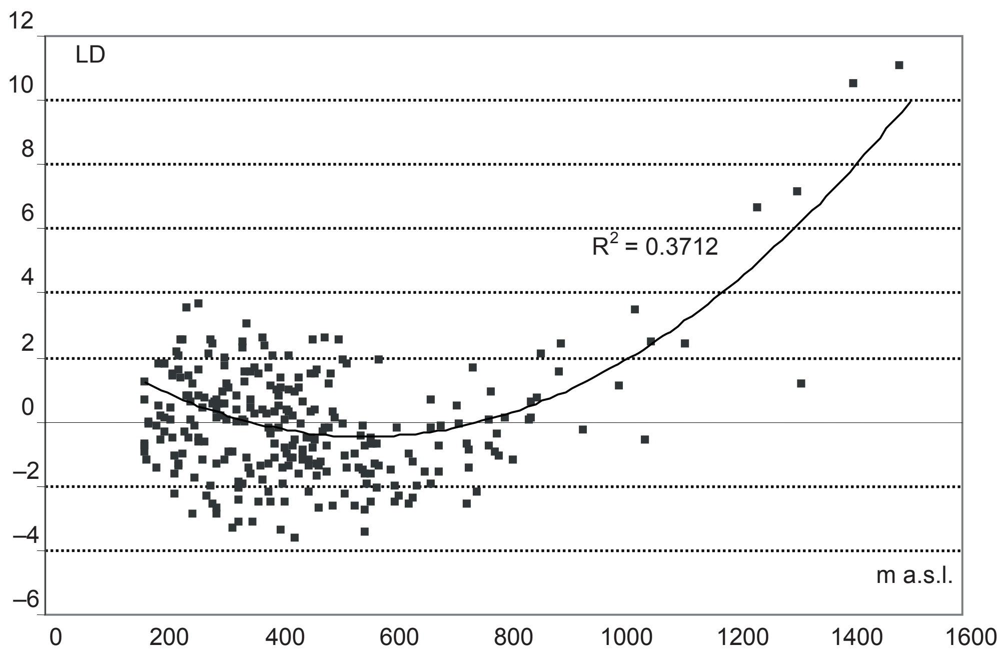

Fig. 3. End of the period with prevailing temperatures 5 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

increase. But average temperatures, for instance, can behave in another way: the average temperature is supposed to be lower over longer periods – since the methods differ in those parts of a year with cold days. It is a more complicated case when the TS method gives the same results for the length of a vegetative period as the CD6 (or CD5) method. In the case of different dates for the beginning and end of the period, then it always holds true that the temperature sums according to the TS method are bigger than the temperature sums for the period estimated by CD6 (or CD5). The explanation for this is that the TS method (method of temperature sums) does not exclude any warm wave and omit colder waves, while the CD method does not work with temperature values themselves, it just estimates the period with a temperature over or below a limit value. Into such a period, the CD method then simply also includes the cold waves and omits the warm waves.

Period with prevailing temperatures above 10 °C

The consecutive days (CD) method was used within the CECILIA project only for the delimitation of the great vegetative period. For its application to the small vegetative period or the vegetative summer (i.e. higher limit values), the usage of this method without any deep analysis is questionable. The problem with higher limits is that, with more and more years, it is not possible to find a given number of consecutive days. In regard to periods with prevailing temperatures above 10 °C, while it was not possible to delimit the vegetative period using the CD6 method in 74 out of all 12,596 cases (15 stations out of all 268 stations), with CD5, it was not possible in only 34 cases (9 stations). The TS method does not put any limitation constraints on the number of days (just one day is sufficient) and, in this case, the small vegetative period was able to be estimated in all cases.

Very shortly, we will mention the percentage of cases in which the methods give the same results. For the timing of the beginning date of the small vegetative period, the results coincide in 57% of the cases for TS and CD6 and in 56% for TS and CD5. CD6 and CD5 coincide in 82% of cases. Dependence on altitude is evident in the results (see Fig. 4). In the average results for stations up to 900 m a.s.l. in the period 1961–2007, the TS method gives a 3-day earlier beginning date to a 9-day later date compared to CD6. For the coldest stations, the TS method shows noticeably later dates than the CD6 method. The explanation is simple: colder years are not included in the CD6 calculation, since the given number of consecutive days was not reached. The results of CD6 are delayed by 0 to 8 days after those of CD5.

Similar results are obtained for dating the end date of a period with prevailing temperatures above 10 °C. The TS method coincides with CD6 in 54% of cases and with CD5 in 55% of cases. CD6 and CD5 coincide in 81% of cases. For average results in lower altitudes, TS and CD6 results are similar (maximal difference is 4 days, for both earlier and later days). For higher altitudes, TS method again delays the end date compared to CD6 method (see Fig. 5). CD6 results show delays of 0 to 13 days (more on stations with higher altitudes) compared to those of CD5.

The length of the small vegetative period is usually shorter by a few days for TS than for CD6 and for

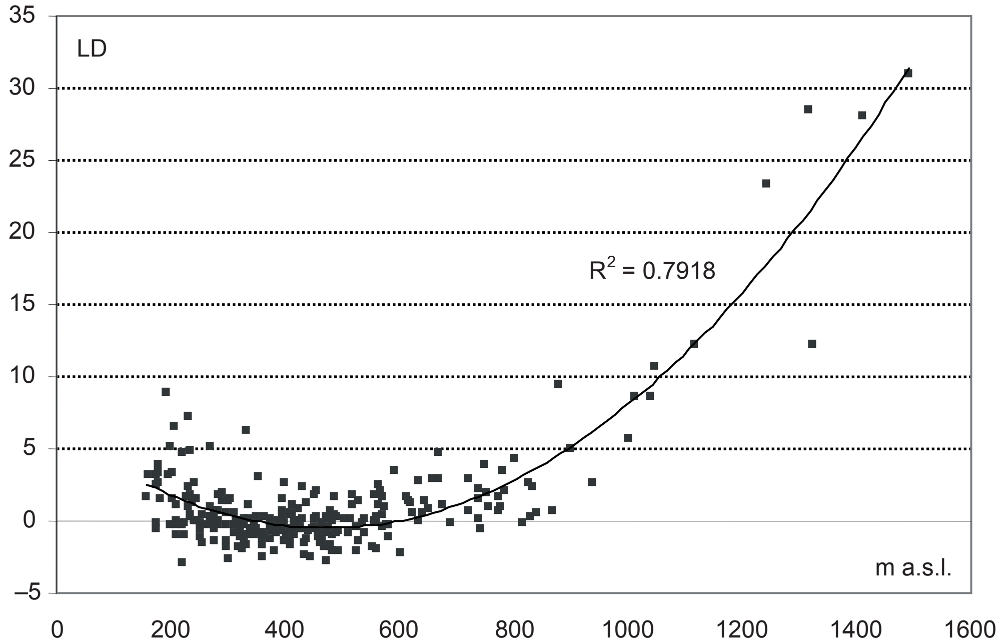

Fig. 4. Beginning of the period with prevailing temperatures 10 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

stations with lower elevations. For higher altitudes, it was the opposite. It is needed to make a remark to these results that in case that the period was not estimated by the method, its length was set to zero.

Period with prevailing temperatures above 15 °C

In the estimation of the vegetative summer, the CD methods face considerable difficulties. For stations with higher elevations, the cases in which a number of 5 or 6 consecutive days is not found is very high: 1,844 cases (15% of all cases) for CD6 and 1,074 cases for CD5. Vegetation summer was able to be established for only 32 stations in all the years between 1961 and 2007 in the case of CD6 method. In the case of CD5 it was 105 stations (out of 268 stations). With the TS methods (where one day with air temperature of 15 °C or more is sufficient), there was only one case in the entire period of 1961–2007 when it was not possible to estimate vegetation summer.

The same beginning date is found with both the TS and CD6 methods in 37% of the cases, with TS and CD5 in 36% of the cases, and with CD6 and CD5 in 75% of the cases. For average results for the period 1961–2007, in comparison to CD6, TS shows delayed beginning dates of the vegetative summer: from 0 days for lower stations and up to 40 days for mountainous stations (see Fig. 6). CD6 method results are also delayed in comparison to those of CD5, but here it is caused by a higher number of cases in which it was not possible to estimate the vegetative summer.

For the end date estimation, TS coincides with CD6 in 31% of the cases, TS and CD5 in 29% of the cases and CD6 and CD5 in 75% of the cases. For average results, in comparison to CD6, TS is delayed up to 24 days for mountainous stations, but for some lowland stations, TS is up to 3 days earlier (see Fig. 7).

In comparison to CD6, TS methods results give the length of vegetative summer shorter by several days for lowland stations. With increasing altitude, this quickly changes, and TS estimates a longer vegetative summer than CD6 for most of the stations (thanks to the fact that the length of the vegetative summer is often zero).

Utilization of long-term averages for the calculation

The last point discussed in this article is the testing of the utilization of long-term averages (1961–2007), i.e. daily normals, for vegetative period dating. In such data, air temperature rises and drops relatively smoothly within a year, and so therefore, the difference in results of various methods should not be as noticeable. This presumption proved true in 85% of the cases in a comparison of the TS method with the CD6 method. In the rest, the maximum difference was 13 days.

If we compare the differences between the individual years and results obtained from long-term averages (daily normals) within the individual methods, we find quite big differences. Generally, the TS method shows smaller differences than CD6 or CD5. Differences in results are least for setting the limits for the period with prevailing temperatures above 5 °C, larger for 10 °C and the largest for 15 °C. For example, with the TS method, temperatures above 5 °C and the beginning date, the maximum difference is 12 days earlier and 6 days later for the daily normals method compared to individual years.

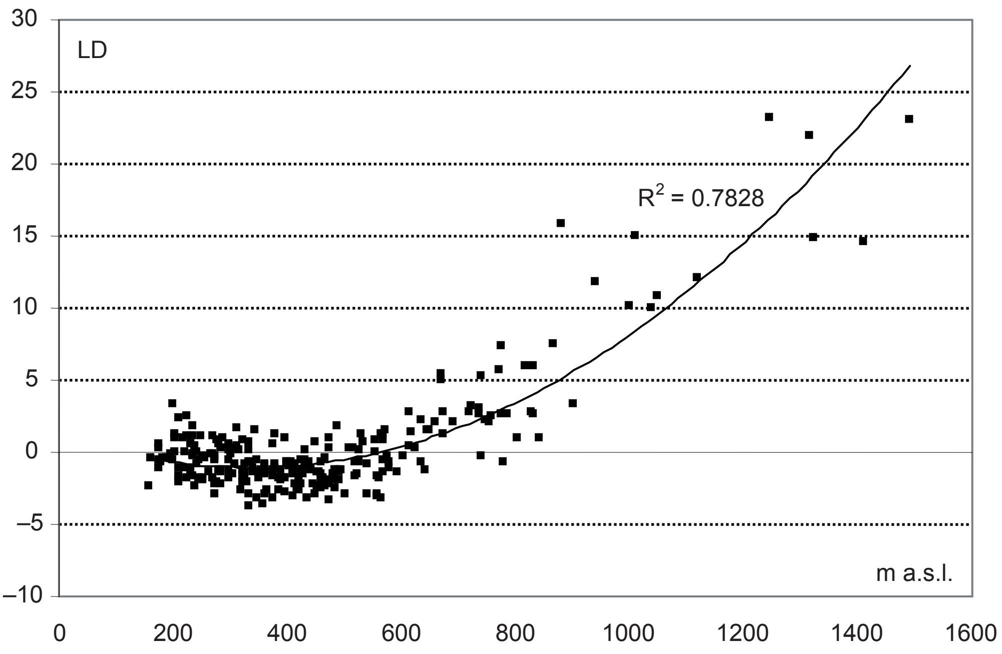

Fig. 5. End of the period with prevailing temperatures 10 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

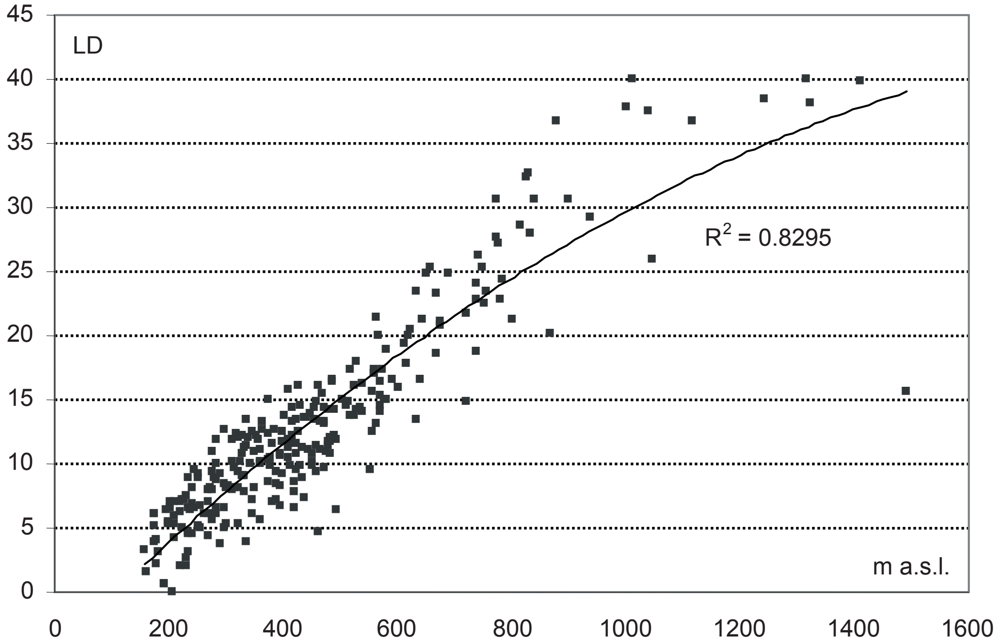

Fig. 6. Beginning of the period with prevailing temperatures 15 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

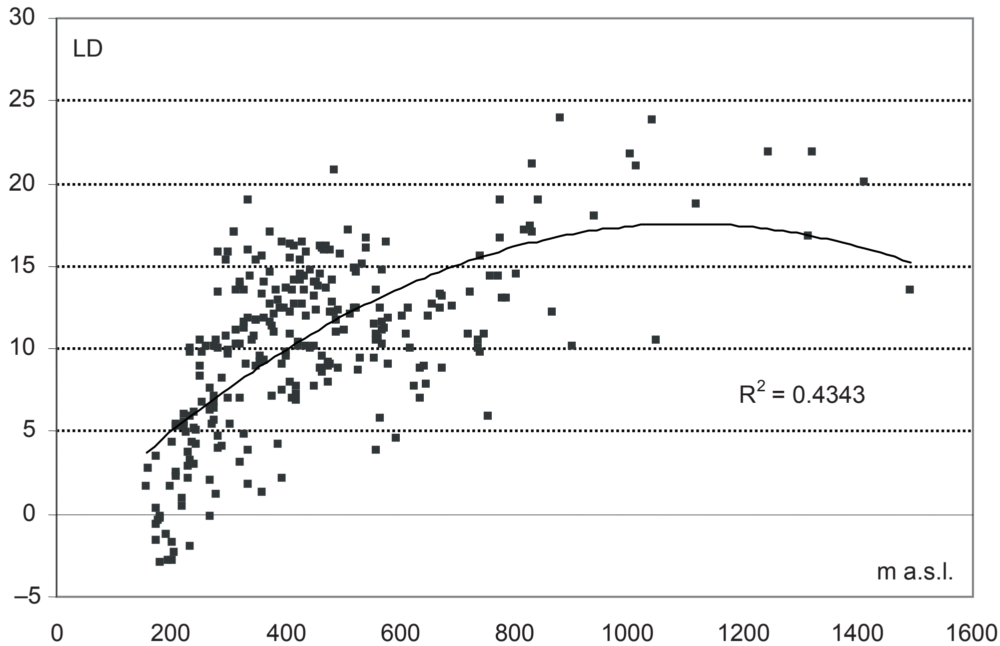

Fig. 7. End of the period with prevailing temperatures 15 °C – differences between sums of temperatures and 6 consecutive days methods, polynom of 2nd degree.

Conclusions

In this work, our aim was to test various methods of dating the vegetative period: a method using temperature sums (TS) and a method using consecutive days (CD6 or CD5). The differences in results obtained by these various methods for various limit values (periods with prevailing temperatures of 5, 10 and 15 °C) were studied on a large dataset of 268 technical series created for the Czech Republic. The percentage in which the results were the same is about 50%, but in individual cases, the differences can be quite huge. The problem with the CD methods is that they may give the start date of a vegetative period in winter after a short thaw; on the contrary, in cases when temperatures fluctuate around 5 °C, the estimate for the beginning date can be very late. Similar problems are faced for the estimation of the end date of the vegetative period. Unlike the TS method, the CD method has another methodological problem and this is the utilization of a "half year", which is set to the end of June. It would be possible to set it to late July, but the fact is that the warmest days of a year can occur in a longer time span. The CD method was unable to estimate the vegetative period in some years (because of 6 or 5 successive days being a condition), while with the use of the TS method, small vegetative periods and even the vegetative summer were found to be longer than 100 days.

Utilization of daily normals (long-term averages) for delimitation of the vegetative period lead to different results compared to calculations for individual years. Thus, such simplification should be only applied with caution.

All the calculations for such a huge dataset were obtained through the use of ProClimDB software (Štěpánek, 2008), which is available on the Internet.

Acknowledgement

This study was supported by a grant from the Ministry of the Environment of the Czech Republic SP/1A6/108/07 "Specification of existing estimates of climate change impacts in hydrology, water management, agricultural and forestry sectors and proposals for adaptation options".

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Vymezení vegetačního období podle průměrných denních teplot vzduchu

Súhrn

K vymezení vegetačního období se často využívá zjednodušeného přístupu pracujícího s průměrnými denními teplotami vzduchu. Velké vegetační období, malé vegetační období a vegetační léto je vymezeno pomocí teplot vzduchu 5, 10 a 15 °C. Samotné vymezení jednotlivých období je ale s ohledem na časté kolísání teploty vzduchu velkým problémem. Předkládaný příspěvek analyzuje a srovnává dvě různé metody určení nástupu a konce

vegetačních období. První z nich je metoda sousedících dnů, kdy se za začátek období bere výskyt prvních n-dní následujících za sebou s teplotou vzduchu rovnou a vyšší teplotě hledaného období. Většinou se pracuje s 5 či 6 dny. Konec období se vyhledá podobně při výskytu n-dní s teplotou nižší než je teplota vymezující hledané období. Druhý přístup je velmi odlišný. Metoda teplotních sum pracuje s konkrétními hodnotami teploty vzduchu a srovnává teplé a chladné vlny (dny s teplotou nad a pod hraniční hodnotou) mezi sebou. Tato druhá metoda se může právem označit jako vynikající metoda sloužící k vymezení období s převládajícími teplotami.

Na datovém materiálu 268 stanic České republiky za období 1961–2007 byly porovnány výsledky jednotlivých metod. Bylo zjištěno, že metoda 6, respektive 5 sousedících dnů a metoda teplotních sum dávají stejné výsledky zhruba v 50 % případů (u teplot 15 °C to bylo méně). Extrémní rozdíly dosahovaly až 100 dní. V dlouhodobých průměrech se rozdíly zmenší, ale jen výjimečně jsou nulové.

Rovněž byla otestována možnost vyhledávání vegetačních období pomocí dlouhodobých hodnot teploty vzduchu. I zde bylo prokázáno, že tento přístup neposkytuje kompatibilní výsledky s přístupem pracujícím s daty jednotlivých let.

Cílem článku bylo, vedle přehledného popisu jednotlivých metod vymezování vegetačních období, ukázat, že různé způsoby hledání téhož mohou a dávají různé výsledky. Tuto skutečnost je nutno respektovat v jakémkoli vědeckém bádání a nedopouštět se případných omylů srovnáváním nesrovnatelného.

Received December 17, 2009
Accepted September 1, 2010