

## Variation in Growing Season Thermal Resources in Central-East Poland

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### ABSTRACT

The work assesses heat resources in central-east Poland (2001–2019). As a measure of heat resources, the concept of growing degree days (GDD) was used. GDD is a useful tool for agriculture as it takes into account the aspects of local weather and, based on it, plant development can be predicted. Daily maximum and minimum air temperatures were used to calculate GDD at 7 stations using threshold base air temperatures of 0°C (commencement of the warm season) and 5°C (start of the period of active plant growth). The following basic characteristics of the distribution were calculated: arithmetic mean, minimum and maximum values as well as coefficient of variation. The direction and significance of changes of the heat resources were determined on the basis of linear trend equations. The significance of directional coefficient of the trend was estimated with t-Student test at the significance level of  $\alpha = 0.05$ . The average air temperature during the growing season ranged from 14.6°C in Białystok and Białowieża to 15.6°C in Włodawa, its greatest increase being recorded in Włodawa and Siedlce (by 0.36°C per year). GDD increased from north to south in the study area, but the mean GDD varied considerably from one location to another. GDD<sub>0</sub> and GDD<sub>5</sub> showed an upward trend over the 2001–2019 period for the study region as a whole.

**Keywords:** Growing Degree Days, growing season, central-east Poland

### INTRODUCTION AND OBJECTIVE OF THE WORK

Increasing global climate warming may lead to considerable changes in plant phenology and, consequently, to changes in agricultural production (Sulikowska et al. 2016). The global research into the effect of climate change on agriculture, horticulture and forestry clearly demonstrates the growing season is becoming longer. At the same time, increasing thermal resources may contribute to an increase in crop production, and improved forest productivity (Linderholm et al. 2008, Trnka et al. 2011, Winkler et al. 2002). An agricultural and climatic division into regions developed in the first half of the 20th century does not take into account a systematic increase in temperature, and requires updating (Skowera et al. 2016). Agricultural adaptation to changing climatic conditions should

include adjusting selection of crop plants to changing thermal conditions and introduction of thermophilic crop plants which are also resistant to draught (Ziernicka-Wojtaszek et al. 2015). In Poland, a rise in the average yearly air temperature has been recorded regardless of region. (Michalska 2011; Żmudzka 2004). An increase in temperature during vegetation is a very important factor in plant development. The increase has been ascribed by Górski and Kozyra (2011), Kożuchowski and Degirmendźić (2005) as well as Ustrnul and Czekierda (2007) to intensified western circulation and influence of the North Atlantic Oscillation (NAO) index. Marsz and Żmudzka (1999) found that the index accounts for 13 to 46% of variation in the growing season length and between several and 61% of variation in the timing of the season's beginning. According to Bartoszek and Węgrzyn (2011), in eastern Poland the NAO index influences 13 to 29% of

variation in the time when the growing season begins. An increase in air temperature during the growing season results in an increase in thermal resources, which may accelerate or delay an occurrence of individual plant development stages (Chmielewski and Rötzer 2001). Determination of Growing Degree Days (GDD), which is the sum of heat above certain thermal thresholds, is an important factor determining the conditions of plant vegetation (Koźmiński and Michalska 2001). Every species has a threshold temperature below which a plant does not develop, and above which the majority of biological processes occur. Temperature also affects the timing of phenological periods such as germination, flowering and maturation. An accumulation of temperature above a given baseline, called Growing Degree Days, is used to estimate plant growth and development as well as the occurrence of insects during the growing season. Moreover, it can be used to predict crop maturity and harvest timing (Kadioglu and Saylan, 2001).

The objective of the present work was to determine temporal and spatial variation of the growing season thermal resources in Poland at the beginning of the 21st century. The GDD index was applied to characterise the thermal conditions.

## RESEARCH MATERIAL AND METHODOLOGY

Analysis was performed for the area of central-east Poland (fig. 1) and was based on mean, minimum and maximum values of daily air temperature obtained from eight meteorological stations ran by Institute of Meteorology and Water Management from 2001–2019.

The GDD index was used to characterise thermal resources:

$$GDD = \sum_{i=1}^m (T_i - T_{base}) \quad (1)$$

$$T_i = (T_{max} + T_{min}) / 2 \quad (2)$$

where:  $T_i$  – mean air temperature (°C) on the  $i$ -th day of the growing season,  
 $i = 1, 2, \dots, m$  – days with temperature higher than the threshold ( $T_{base}$ , °C),

$T_{max}$  and  $T_{min}$  – daily maximum and minimum air temperatures (Bootsma 1994, Gordon and Bootsma 1993, McMaster and Smika 1988, McMaster and Wilhelm 1997, Snyder et al. 1999).

GDD was determined for three periods: above 0°C, 5°C and 10°C (respectively, the period outside of winter, the growing season and the period of active plant growth).

Basic distribution characteristics were calculated: arithmetic mean, minimum and maximum values and coefficient of variation. The direction and significance of tendencies of change in the analysed parameters were determined based on linear trend equations. Significance of the directional coefficient of the trend was estimated with t-Student test at the significance level of  $\alpha = 0.05$ .

Maps of variation in the directional coefficients of trend in the GDD changes were drawn up for three periods analysed in central-east Poland. Ordinary kriging was used, as in many conventional climatological approaches it is believed to be the only spatial interpolation method. The general assumption kriging relies on is the presence of internal stationarity across the whole so-called spatial field. Explanatory values (variables) are based on linear equations calculated from the observational data with weights attached. The weights are dependent on the spatial correlation existing between these points. Linear coefficients are computed so as to ensure the lowest estimated variance error (the so-called kriging variance). Owing to these features, kriging is believed to be the most universal method of spatial analysis (Walsh and Lawler 1981).



Fig. 1. Study area

## ANALYSIS OF RESULTS

The temperature throughout the growing season in central-east Poland, when averaged across 2001–2019, was 15.1°C. The lowest temperature for this period was recorded in the northern-east area of the region. The respective values of this parameter were 14.6, 14.6 and 14.7°C for the stations in Białystok, Białowieża and Szepietowo. The warmest growing seasons were observed in Włodawa and Terespol (respectively, 15.6 and 15.5°C) (Tab. 1).

Of the analysed periods, the highest mean values of thermal resources were found for the period outside of winter ( $GDD_0$ ), and the lowest for the period of active plant growth ( $GDD_{10}$ ). On average, thermal resources during the

growing season in central-east Poland amounted to:  $GDD_0 = 2800.2$ ,  $GDD_5 = 1896.6$  and  $GDD_{10} = 1055.2$ . They were found to differ according to location. In Szepietowo, their values in all the analysed thermal periods were similar to the mean for the whole region. By contrast, they were far higher in Włodawa and much lower in Białowieża. The highest  $GDD_0$  and  $GDD_5$  were recorded at the Pułtusk station (respectively, 2840.3 and 2304.5°C), and the highest  $GDD_{10}$  in Legionowo and Włodawa (respectively, 1165.0 and 1118.9°C). The lowest thermal resources were determined for Białystok and Białowieża:  $GDD_0$  (respectively, 2686.2 and 2694.1°C),  $GDD_5$  (respectively, 1786.6 and 1793.8°C) and  $GDD_{10}$  (respectively, 960.8 and 966.3°C) (Table 1, Fig. 2).

**Table 1.** Descriptive statistics characterising the GDD index (°C) during the growing season in central-east Poland in 2001–2019

Station	Parameter	$GDD_5$	$GDD_{10}$	$GDD_0$	Air temp. in Apr-Sept
Białystok	Mean	1786.6	960.8	2686.2	14.6
	Max.	2173.9	1290.4	3085.0	16.8
	Min.	1523.4	726.2	2427.0	13.2
	V (%)	7.5	12.5	5.0	5.1
Siedlce	Mean	1903.4	1060.1	2807.9	15.2
	Max.	2219.8	1333.9	3132.6	19.8
	Min.	1668.4	840.7	2577.1	8.1
	V (%)	6.1	10.0	4.2	24.2
Terespol	Mean	1956.8	1108.1	2862.3	15.5
	Max.	2292.9	1403.1	3205.5	20.2
	Min.	1694.8	873.0	2601.5	8.5
	V (%)	6.3	10.2	4.3	23.8
Włodawa	Mean	1967.7	1118.9	2873.1	15.6
	Max.	2304.1	1414.2	3216.1	20.2
	Min.	1708.3	877.4	2614.4	8.3
	V (%)	6.4	10.4	4.4	24.1
Białowieża	Mean	1793.8	966.3	2694.1	14.6
	Max.	2100.0	1216.1	3012.5	19.5
	Min.	1558.1	760.2	2455.8	7.1
	V (%)	6.6	10.9	4.5	26.6
Legionowo	Mean	2020.7	1165.0	2927.4	15.5
	Max.	2413.4	1520.4	3327.5	19.4
	Min.	1772.5	920.1	2682.2	8.4
	V (%)	7.0	11.4	4.8	22.0
Pułtusk	Mean	1918.6	1072.0	2823.7	15.4
	Max.	2304.5	1415.7	3218.2	20.1
	Min.	1665.6	820.1	2574.6	8.1
	V (%)	7.3	12.2	4.9	24.7
Szepietowo	Mean	1825.3	990.7	2727.0	14.7
	Max.	2139.1	1257.0	3052.6	16.5
	Min.	1540.3	728.5	2444.9	13.2
	V (%)	7.2	11.6	4.9	5.4

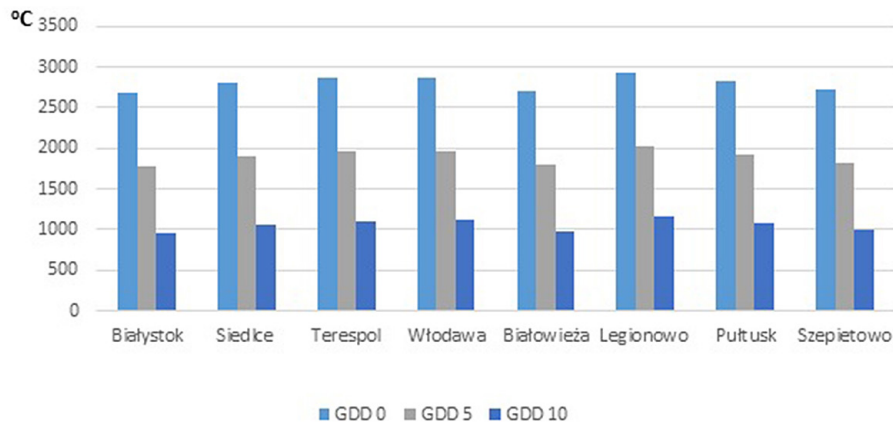


Fig. 2. Mean values of the GDD index (°C) during the growing season in central-east Poland in 2001–2019

The greatest variation in thermal resources occurred during the period of active plant growth ( $GDD_{10}$ ), which is indicative of greater thermal instability during the warm season of the year. Coefficient of variation ranged from 10.0 to 12.5% for Siedlce and Białystok, respectively. In the study area, the mean  $GDD_0$  and  $GDD_5$  variation values were 4.6 and 6.8%, respectively. Wypych et al. (2017) analysed the GDD values for the whole of Poland and found regional differences for different temperature bases. The greatest spatial variation was determined for the sums above the temperature threshold of 0°C. For the thresholds 5 and 10°C, the variation range was narrower and their spatial distribution was far less uniform. The authors report that such spatial distributions underline the importance of continental influences, particularly in the eastern part of the country.

Linear regression coefficients were used to estimate the tendencies in changes in thermal conditions during the three analysed periods. All the directional coefficients of trend in GDD changes were positive, which is indicative of an increase in thermal resources and confirms the existence of an overall trend associated with climate warming (Fig. 3, 4 and 5). Sulikowska et al. (2016) also found a statistically significant positive tendency of changes in thermal resources in Poland, the situation in its central-north area being particularly advantageous as the increase is twice as high as the average change observed for the whole of Poland. Matzarakis et al. (2007) reported an upward trend in GDD values in Florina, Greece, in 1978–1987. In turn Kadioglu and Saylan (2001) found spatially uniform, statistically significant downward trends in GDD in the Turkish coastline areas during summer and autumn.

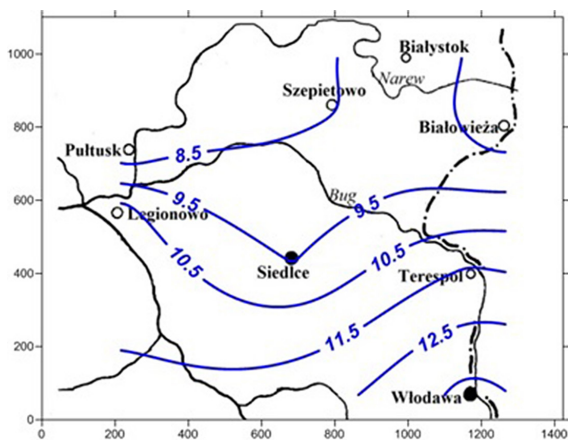


Fig. 3. Spatial distribution of the directional coefficients of the trend in changes in  $GDD_0$  (°C) during the growing season in central-east Poland in 2001–2019

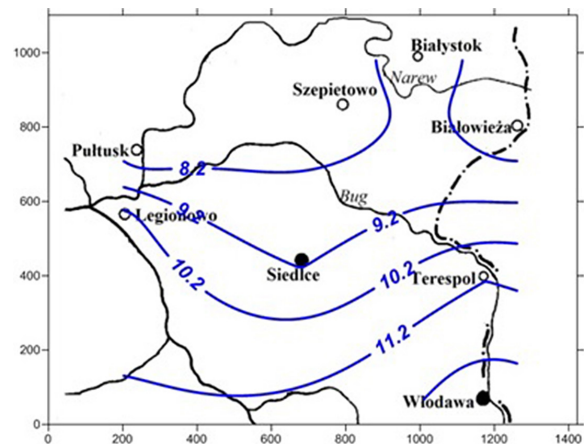
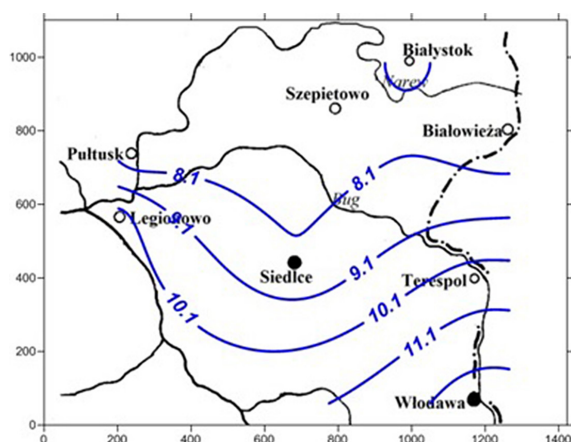


Fig. 4. Spatial distribution of the directional coefficients of the trend in changes in  $GDD_5$  (°C) during the growing season in central-east Poland in 2001–2019



**Fig. 5.** Spatial distribution of the directional coefficients of the trend in changes in  $GDD_5$  ( $^{\circ}C$ ) during the growing season in central-east Poland in 2001–2019

The trend in changes in the GDD values for all the thermal periods in central-east Poland in 2001–2019 was found to be spatially variable. The greatest increase in thermal resources in all these periods occurred in the southern-east area of the region, and it declined northwards. Of the three thermal periods analysed, the greatest increase was recorded for the  $GDD_0$  values (by around  $13.5^{\circ}C$  per year in Włodawa). An increase in  $GDD_5$  was similar to  $GDD_{10}$  and they both were by about  $1^{\circ}C/year$  lower compared with  $GDD_0$ .

## CONCLUSIONS

Substantial variation was observed in the  $GDD_0$ ,  $GDD_5$  and  $GDD_{10}$  values. In all the analysed thermal periods, they were very similar to the mean for the whole area, being much higher in Włodawa. Temporal variation in GDD from April to September revealed positive temporal changes throughout 2001–2019, which confirms the overall warming trend. Of the three thermal periods analysed, the highest year-to-year increases were recorded for the  $GDD_0$  values.

The results of the work reported here may be utilised to evaluate the temperature-related characteristics of the study area climate during the growing season. Additionally, they may be an information source used for optimum plant production management. The GDD index may be used for assessing the potential increase and probability of successful cultivation of a given species.

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