DOI:10.28974/idojaras.2022.3.3

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 126, No. 3, July – September, 2022, pp. 319–334

Frequency and variability trends of extreme meteorological events in theMoson Plain, Hungary (1961–2018)

Tamás Füzi and **Márta Ladányi**

Hungarian University of Agriculture and Life Sciences
Department of Applied Statistics
Villányi út 29-43, 1118 Budapest, Hungary

**Corresponding author E-mail: fuzi.tamas@kertk.szie.hu*

(Manuscript received in final form June 11, 2021)

Abstract— Corresponding to the global trends, the territory of Hungary is endangered by extreme weather manifestations. The increased frequency of the unfavorable effects (inland water, flood, drought, heat stress) can be detected. These harmful manifestations result in a significant economic and environmental risk. To investigate adverse environmental effects and risks that have an impact on economic and productive activities is essential. The aim of our research is to present the transformation of the climatic system of the Moson Plain in the northwestern part of Hungary by analyzing special indicators based on daily temperature and precipitation data covering approximately two climatic cycles (1961–1990; 1991–2018). Based on our results, we can report the formation of a warming microclimate with whimsical precipitation rates, which is accompanied by a decrease in low temperature values. At the same time, we can observe more prominent manifestations of heat waves.

Key-words: climate change, Moson Plain, heat waves, drought, frost-free

1. Introduction

The global change of the climate system has different effects at the regional and local levels. The analysis and subsequent evaluation of past manifestations is the most important task, as regional measurements and modeling are the best ways to reproduce the climatic characteristics of a large geographical area, such as the Carpathian Basin (*Illy et al.*, 2015).

Regional consequences of climate change manifestations are also of increased importance, because the climate sensitivity and vulnerability of the Carpathian Basin and Hungary are unique, and this region is extremely vulnerable to weather conditions.

Climate change is not just about rising temperatures. In the future, we need to anticipate and prepare for more and more frequent and intense manifestations of exaggerated and extreme weather events (*Ummenhofer* and *Meehl*, 2017). These are the changes to which our social and economic systems have to adapt to (*Buzási et al.,* 2018). The significance of this lies in their dependence on the weather. Such changes in the climate system affect the successful operation and fertility of many areas, from landscape, natural geography and hydrography to public welfare and provisioning opportunities.

These changes are mainly reflected in the alteration of temperature and precipitation data, which show the shift of vegetation zones (*Dunkel et al*., 2018; *Gáborjányi et al*., 2007), and the prolongation of vegetation periods (*Jolánkai et al.*, 2016). The transformation of cultivation conditions and the distortion of regional weather conditions are also faced.

We investigated the signs of climate system change and explored the consequences and effects of these changes, in order to precisely identifying the need of adaptation to adverse conditions. In the present study, we analyze the microclimate of the Moson Plain in the northwestern part of the country based on temperature and precipitation data of the past nearly 60 years, with a particular focus on changes in the frequency of extreme events. We do all this in order to supply producers, farmers, and other actors of the economy with information that helps them carry out successful and productive work for the national economy, in spite of adverse environmental factors.

2. Literature review

The rise in the concentration of atmospheric pollutants, which was considered drastic as early as the middle of the 20th century, was noted by *Landsberg* (1979) nearly half a century ago. It was mentioned in regard of global warming, which was confirmed by Flohn in his 1980 study (*Flohn*, 1980). Since then, climate change has been the subject of numerous international and Hungarian scientific publications, which have become more and more complex and severe over the years. *Faragó et al.* (1990) drew a clear parallel between human activity and climate change, global warming, and the emergence of extreme weather events and their signs in Hungary. According to a 2019 report by the World Meteorological Organization, 2019 was the second warmest year since the start of instrumental measurements, with global average temperatures 1.1 °C higher than pre-industrial temperatures. Furthermore, the decade of 2010–2019 was found to be the hottest ten years since 1850 (*WMO*, 2019).

According to a report by the European Environment Agency, Europe is also experiencing continued warming (*EEA*, 2017) and the accompanying increase in the number of hot days (*EEA*, 2018). This phenomenon is particularly harmful to our daily lives, and it may lead to other extreme atmospheric conditions and adverse environmental changes. These may include, but are not limited to, rising land and ocean temperatures, changes in rainfall distribution, inland watering in some areas, or even droughts, all of which can adversely affect the environment throughout the year (*Mika*, 2018; *Nordhaus*, 2019). Droughts in Europe were most pronounced in the Mediterranean and the Carpathian Basin, with an increase in frequency, severity, and duration since the 1950s (*Spinoni et al.*, 2015a). According to *Gosic* and *Trajkovic* (2013), droughts occurring every 3–5 years are the greatest environmental threat in the Carpathians, and it is also becoming a global problem due to increasing global warming (*Maracchi*, 2000; *Spinoni et al.*, 2015b). According to *Bozó et al.* (2010), an additional risk is that the Carpathian Basin is one of the most climate-sensitive areas. Climate change is expressed in a unique way due to territorial heterogeneity, as different climatic zones exert their effects on radically different regions (*Gelybó et al*., 2018).

According to the report of the Hungarian Meteorological Service, the average temperature in Hungary has increased by more than 1.1 °C since 1901, but in recent decades (since 1981), the increase in average temperature has become even more intense (1.97 °C between 1981 and 2016), which varied between 1.2 and 1.8 °C in different parts of the country, and became particularly strong in the heat wave days typical during the summer months (*Bartholy et al*., 2011; *Lábó et al.,* 2018). According to *Pálvölgyi et al.* (2011), 52% of Hungary's territory is particularly vulnerable to heat waves, and this is in line with Hoyk's (2015) statement that the regional climate models (ALADIN-Climatemodel, REMO-model, PRECIS-model, RegCM-model) used in Hungary, forecast a significant increase in temperature by 2050. Thus, throughout the territory of Hungary, the unfavorable effects of climate change and the extreme manifestations of weather occurrences (heat waves, hot days) are becoming more and more typical. This means that the average temperature of the annual and summer days will increase significantly, while the number of frost winter days and the average rainfall during the summer will decrease greatly (*Uzzoli*, 2015).

As a result of climate change in Central Europe, and also in Hungary, we have to reckon with wetter and milder winters and drier summers with higher average temperatures (*Sassi et al*., 2019; *Feurdean et al.,* 2020).

Consequently, water shortage can be expected to become more severe as heat causes an increase in the water consumption, which is accentuated by declining rainfall and increasing evaporation at the surface of water and soil. During the drought period, the moisture of the soil decreases, with which the groundwater level drops (*Harnos* and *Csete*, 2008). Temporal and spatial fluctuations of meteorological conditions can affect soil conditions, water supply, and agricultural yields (*Boubacar*, 2010; *Łabędzki* and *Bąk*, 2017). It can also accelerate the spread of new types of pests and pathogens (*Szabó* and *Fári,* 2017; *Bánáti,* 2019). In warmer climates, the activity and geographical spread of pests are also changing, which may lead to increased use of agrochemicals, accompanied by increasing health, ecological, and economic difficulties (*Rosenzweig et al*., 2001).

This process indicates that crop production must face the challenges posed by climate change and the cumulative negative effects as the transformation of the climate system is projected to be accompanied by rapidly rising temperatures, more frequent droughts, and other hydroclimatic extremes (*Pinke* and *Lövei*, 2017). As such, the crop production sector needs to be prepared for the more frequent water shortages, the drought stress caused by the intensifying heat waves, and the associated significant crop losses (*Challinor et al*., 2010; *Teixeira et al.*, 2013). All of these extremes, associated with climate change, affect continental climate berry fruits in highly unfavorable ways, as in the ripening phase – in the warmest and driest phase of the year –, the leaf and fruit scorching of plants can result in decreased photosynthesis, decline in plant development, and crop loss (*Keller et al.*, 2017).

However, the adverse effects of the consequences of climate change diverge considerably from region to region depending, among other things, on differences in biophysical resources, farming, adaptability, or even crop production. These experienced and observed adverse effects could lead to further territorial differentiation in a situation, where inequality already exists. As such, the less well-conditioned areas, which are still experiencing economic difficulties, may fall further behind due to a lack of resources (*Lobell et al.,* 2008; *Bognár* and *Erdélyi*, 2018).

Therefore, according to *Mcleman* and *Smit* (2006), we need to focus not only on understanding the climate system but also on the dangers of climate change manifestations, as these changes represent physical hazards that manifest in extreme forms.

3. Data and methods

In our study, we investigated the changes in weather conditions of the Moson Plain. Daily data (average, minimum, maximum temperature (°C) and precipitation (mm)) for this area were requested from the database of the local measuring station in Mosonmagyaróvár, maintained by the Hungarian Meteorological Service. Our research takes approximately two climatic cycles into consideration: the reference period 1961–1990 and the recent time zone 1991–2018.

Based on indicators formed from various temperature thresholds, we examined their frequencies of occurrences (days) in 30 and 28 years on a monthly basis.

The following temperature indicators were examined (days):

- Extremely hot days (T_{max}>35 °C): the maximum daily temperature was above 35 °C,
- Hot days (30°C<T_{max}<35 °C): maximum daily temperature was between 30 °C and 35 °C,
- Summer days (25 °C<T_{max} 30 °C): maximum daily temperature was between 25 °C and 30 °C,
- Mild days (0 °C<T_{max}<25 °C): maximum daily temperature was between 0 °C and 25 °C,
- Winter days (T_{max}<0 °C): maximum daily temperature was below 0 °C,
- Tropical nights (T_{min}>20 °C): the minimum night temperature was above 20 °C,
- Warm nights (18°C<T_{min}<20 °C): the minimum night temperature was between 18 °C and 20 °C,
- Frost days (-5 °C<T_{min}<0 °C): the daily minimum temperature was between -5 °C and 0 °C,
- Hard frost days (-15 °C<T_{min}<-5 °C): the daily minimum temperature was between -15 °C and -5 °C, and
- Extremely frosty days (T_{min}<-15 °C): the daily minimum temperature was below -15 °C.

In addition to the above, in the time interval between April and September, we examined the lengths (days) of the three longest continuously precipitation-free periods of the years. We also examined the lengths (days) of the precipitation periods immediately preceding and following the precipitation-free periods and the amount (mm) and average (mm) of precipitation during these time intervals as well.

We examined and illustrated the change in the length of the precipitation-free periods according to time categories (shorter than 7 days, 8–10 days, 11–14 days, and longer than 2 weeks). Our analyses were performed on a monthly basis, and the changes were summarized for the reference period 1961–1990 and the recent time period 1991–2018.

Two-sample ratio test (Z-test) was used to compare the differences of the occurrence frequencies (i.e., the temperature indicator values) between the reference period and the recent climate cycle. We also performed frequency analysis with cross-tabulation (Chi-square tests) to compare the time intervals 1961–1990 and 1991–2018, according to the distributions of the three longest precipitation-free periods between April and September, in Mosonmagyaróvár. In the case of precipitation indicators, linear trend analysis was also performed: using Student's t tests for the linear regression slopes, we tested whether they showed significant change. The distributions of lengths of the three longest precipitation-free periods are compared also by Chi-square test (cross-tabulation).

4. Results

Our results obtained by evaluating the temperature data are shown in *Tables 1–3*. These tables show the temperature indicators we have defined, the Z-values obtained by the statistical tests, the directions of changes, the levels of significances of the changes, the occurrences experienced in climate cycles by decades expressed in days, and the extents of changes between the two climate cycles.

Table 1 shows the indicators formed from the daily maximum temperature values.

The number of days with maximum temperatures (summer, heat, and hot between 25–30 °C, 30–35 °C, and above 35 °C, respectively) show an increasing trend. This change is typically significant in the spring-summer months ($p<0.05$). Among the examined indicators, the number of extremely hot days ($T_{max}>35$ °C) increased the most, the change was also significant in June-July and August ($p<0.001$).

Their number – by the end of summer, in August – in the recent climate cycle (1991–2016) – increased more than 20-fold compared to the reference period (1961–2016) (*Table 1*). This implies a notable risk of temperature rise and heat stress, which is also supported by Németh's (2019) study, according to which, an increase in the frequency of heat waves and average annual temperature in Vas and Győr-Moson-Sopron counties can be observed and experienced by producers.

Table 1. Frequencies of maximum temperature indicators for two climate cycles (1961–1990; 1991–2018): the significance level of the change (Z-value), direction and extent of change within the climate cycle (days) and in the comparison of the two climate cycles (Mosonmagyaróvár)

Indicators	Months	Z-value	Direction of change between the two climate cycles	Decade average incidence (days) (1961–1990)	Decade average incidence (days) (1991–2018)	The change between the two climate cycles
Extremely hot days T_{max}>35 °C	June-July	4.105***	increasing	1	9	6.7
	August	5.98***	increasing	<1	14	20.4
Hot days 30 °C<T_{max} <35 °C	April-May	3.30***	increasing	1	6	6.1
	June	6.16***	increasing	18	45	2.5
	July	6.71***	increasing	50	91	1.8
	August	4.88***	increasing	42	69	1.7
	September	0.83ns		6	6	
Summer days 25 °C<T_{max} <30 °C	April-May	4.28***	increasing	65	95	1.4
	June	2.44*	increasing	102	119	1.2
	July	0.12ns		128	127	
	August	2.04*	increasing	121	135	1.1
	September	1.86ns		56	66	
	October	0.56ns		4	5	
Mild days 0 °C<T_{max} <25 °C	January	2.96**	increasing	196	217	1.1
	February	1.68ns		235	244	
	March	1.06ns		300	303	
	April	1.74ns		290	285	
	May	4.63***	decreasing	254	225	0.9
	June	6.21***	decreasing	180	135	0.8
	July	6.66***	decreasing	130	84	0.6
	August	7.64***	decreasing	147	93	0.6
	September	1.81ns		238	228	
	October	0.56ns		47	39	
	November	0.67ns		291	289	
	December	2.23*	increasing	230	244	1.1
Winter days T_{max}<0 °C	January	2.96**	decreasing	114	93	0.8
	February	1.61ns		47	39	
	March	1.06ns		10	7	
	November	0.67ns		9	11	
	December	2.23*	decreasing	94	66	0.7

In contrast to the increase in the number of extremely hot, hot, and summer days, the number of mild days (T_{max} 0–25 °C) free from extreme heat, decreased significantly in the late spring-summer months ($p<0.001$). The reason for this change is that non-extreme and risk-free days have been replaced by high and extremely high temperature days associated with intense warming (*Table 1*).

Table 1 also shows a special category of frost days (referred to ‘winter days’), when even the daily maximum temperature does not reach 0 °C. The number of such days in late autumn (November) and late winter - early spring (February and March) has not changed significantly during the past nearly 60 years ($p>0.05$). However, during the dormant period (December and January), their number decreased significantly ($p<0.05$) in Mosonmagyaróvár in the recent climate cycle (1991–2018) compared to the reference period (1961–1990).

The disappearance of frosts together with the less frequent appearance of snow-cover, are accompanied by a transformation of the ecosystem structure, the phenomenon of plant species shifting further north (*Bokhorst et al.,* 2008). The lack of winter days results in a warming and drying environment, intensified evapotranspiration processes during the dormant period, and, due to the insufficient development of frost tolerance, leads to increased frost sensitivity and early loss of resistance (*Lun et al*., 2020). This result was also reached by *Ferguson et al.* (2011). Using a thermal time model, he estimated the temperature thresholds required to achieve frost tolerance of three grapevine varieties are between 4.25 °C and 5.75 °C, i.e., the thresholds below which the chilling effect can prevail.

According to *Horváth* and *Komarek* (2016), in the temperate zone, some perennial cultivars may require a minimum temperature sum during the dormant period below -6 °C, which, if not obtained, may cause similar degree of damage as too high temperatures.

In parallel with the increasing frequency of high-temperature days, during the past nearly six decades, the time interval of potential high temperature occurrences also widened from the late spring months to the early autumn months. In contrast, the occurrence of lower temperature (winter) values within a year has become rarer, and the appearance of such values narrowed down to an ever-shorter period. The occurrences of indicators determined by daily minimum temperature values are shown in *Table 2*.

Table 2. Frequencies of minimum temperature indicators for two climate cycles (1961–1990; 1991–2018): the significance level of the change (Z-value), direction and extent of change within the climate cycle (days) and in the comparison of the two climate cycles (Mosonmagyaróvár)

Indicators	**Months**	**Z value**	**Direction of change between the two climate cycles**	**Decade average incidence (days) (1961–1990)**	**Decade average incidence (days) (1991–2018)**	**The change between the two climate cycles**
Tropical nights T_{min}>20 °C	July	4.70***	increasing	2	12	6.1
	August	3.23**	increasing	2	8	3.9
Warm nights 18 °C<T_{min} <20 °C	May	1.42ns		0	1	
	June	3.19**	increasing	9	17	1.8
	Jule	4.93***	increasing	16	35	2.3
	August	4.68***	increasing	16	35	2.2
	September	2.23*	increasing	1	3	4.8
Frost days -5 °C<T_{min} <0 °C	January	0.42ns		127	130	
	February	1.50ns		114	125	
	March	0.61ns		92	96	
	April	0.06ns		23	24	
	May	1.05ns		2	1	
	October	1.48ns		30	24	
	November	0.52ns		83	81	
	December	1.48ns		140	129	
Hard frost days -15 °C<T_{min} <-5 °C	January	3.42***	decreasing	107	84	0.8
	February	0.31ns		60	58	
	March	1.64ns		21	15	
	October	0.71ns		3	2	
	November	2.20*	decreasing	17	10	0.6
	December	0.99ns		64	58	
Extremely frost days T_{min}<-15 °C	January	3.09**	decreasing	12	5	0.4
	February	1.95ns		6	3	
	December	1.30ns		2	4	

In general, the number of days with different strengths of frost (frost days, hard and extremely frost days T_{min}<0 °C) decreased, although in terms of their frequency, in most cases, the change between the two climate cycles (1961–1990; 1991–2016) was not significant (p>0.05). There was no significant change in the number of frost days (-5 °C<T_{min}<0 °C) during any month (p>0.05). However, the number of hard frost days (-15 °C<T_{min}<-5 °C) decreased significantly in January and November

($p<0.001$; $p<0.05$). The frequency of extremely frost days ($T_{min}<-15$ °C) fell to less than its half in January for the recent climate cycle (1991–2018, $p<0.01$).

Among the daily minimum temperatures, special attention should be paid to the increase in the number of hot events ($T_{min}>20$ °C), that is also referred to in the literature as a tropical night (*Cantos et al*., 2019). Changing its frequency is one of the greatest risk factors in agriculture, because tropical nights are more injurious to crop quality, plant growth, and development than daytime heat (*Ryu et al*., 2017). In our analytical work, we found that, compared to the reference period (1961–1990), the number of tropical nights in the recent climate cycle increased more than sixfold in July and approximately fourfold in August (*Table 2*). The change was significant in both cases ($p<0.001$).

Of the nights without adequate cooling, the number of warm nights (18 °C<T_{min}<20 °C) increased significantly in all the three summer months ($p<0.01$): 1.8 times in June and more than twice in July and August. The incidence of nights with heat stress was no longer limited to the summer months (*Table 2*), but also extended to the first autumn month: in September, in the recent climate cycle (1991–2018), their number increased approximately five-fold ($p<0.05$).

Table 3. Minimum, maximum, mean, variance and range of the annual frequencies of the examined indicators for 28 and 30 years in the reference and recent periods (1961–1990; 1991–2018) in Mosonmagyaróvár

Indicators	**1961–1990**					**1991–2018**				
	min	**max**	**mean**	**variance**	**range**	**min**	**max**	**mean**	**variance**	**range**
Extremely hot days Tmax>35 °C	0	2	0.20	0.55	2	0	14	2.25	3.44	14
Hot days 30 °C<Tmax<35 °C	2	20	11.70	5.22	18	3	40	21.79	9.65	37
Summer days 25 °C<Tmax 30 °C	28	69	47.60	9.97	41	33	85	54.79	11.78	52
Mild days 0 °C<Tmax<25 °C	234	311	279.73	18.50	77	236	285	265.00	12.99	49
Winter days Tmax<0 °C	7	63	26	11.88	56	4	50	21.68	9.68	46
Tropical nights Tmin>20 °C	0	3	0.40	0.72	3	0	9	2.64	2.45	9
Warm nights 18 °C<Tmin<20 °C	0	10	4.07	2.82	10	1	20	9.18	5.26	19
Frost days -5 °C<Tmin<0 °C	39	96	61.23	12.49	57	39	82	60.79	12.33	43
Hard frost days -15 °C<Tmin<-5 °C	0	58	27.13	11.34	58	7	40	22.75	9.96	33
Extremely frost days Tmin<-15 °C	0	13	2.23	3.39	13	0	10	1.18	2.04	10

The average, the variance, and the range of the occurrences of high temperature days (extremely hot days, hot days, summer days, tropical nights, and warm nights) also increased in the recent climate cycle (1991–2018, *Table 3*). This means that the events defined by the examined indicators have become more frequent. Furthermore, the exaggerated manifestations of extreme high temperature events and their increasingly unpredictable recurrence have become commonplace. In many cases, the maximum annual frequencies of the examined indicators doubled (T_{max} 30–35 °C; T_{min} 18–20 °C), tripled (T_{min}>20 °C), or even increased sevenfold (T_{max}>35 °C) for the 1991–2018 climate cycle. As a result, the appearance of some extreme high temperature events become more and more uncertain year by year. Therefore, preparing for and defending against the adverse effects of extreme weather events form a great and unavoidable challenge.

In contrast, the average, the variance, and the range of the extreme-free mild days (T_{max} 0–25 °C) and low-temperature days (frost, hard frost, and extremely frost days) have decreased over the past three decades (1991–2018, *Table 3*). This means that low temperature values have become decreasingly frequent and more predictable in the time periods studied.

Xie et al. (2015) also confirmed that the frequency and the probability distribution of extreme weather events associated with warming are also changing across the globe, which may even manifest itself in an unfavorable form (flooding rain, prolonged drought).

To analyze the occurrence of long precipitation-free periods (daily precipitation<1 mm), we first calculated the lengths (days) of the three longest and uninterrupted precipitation-free periods in both cycles (1961–1990; 1991–2016) between April and September. We also examined the characteristics of precipitation periods directly before and after these periods, such as their lengths (days) and the amount (mm) and average (mm) of precipitation during these time intervals. The lengths of the long precipitation-free period were split into four categories: shorter than 7 days, 8–10 days long, 11–14 days long, and longer than 2 weeks.

Using linear trend analysis, we have found that in the period 1961–2018, considering the time intervals before and after the three longest precipitation-free periods between April and September, the change in the lengths of precipitation periods (before: slope<0.000 p=0.967; after: slope=-0.003; p=0.551), the amount of precipitation (before: slope=0.097 p=0.107; after: slope=-0.004 p=0.944), and the average of precipitation (before: slope=0.039 p=0.053; after: slope=-0.008 p=0.708) were not significant. The same insignificant result was found when we considered the change in the number of days during the three longest continuous rainless periods in the last nearly 60 years (first: slope=0.043 p=0.371; second: slope=0.017 p=0.434; third: slope=0.036 p=0.066).

The distribution of lengths of the three longest precipitation-free periods is expressed in percentages in *Fig. 1*. The distributions of the three longest precipitation-free periods in the two cycles differ significantly ($Khi^2(3)=12.58$;

p<0.01). The first three longest precipitation-free periods lasting less than seven days occurred most frequently (33%) in the reference period (1961–1990) and the most rarely (13%) in the recent climate cycle (1991–2018). This change was significant ($Z=3.32$, $p<0.001$).

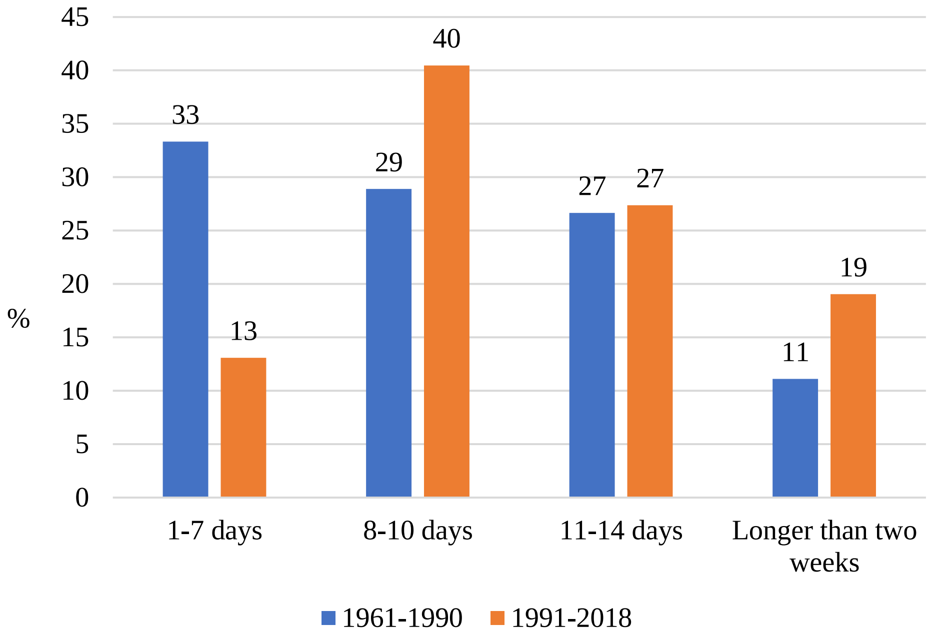

Fig. 1. Distribution of the length of the three longest precipitation-free periods between April and September, expressed in percentages (1961–1990 and 1991–2018 Mosonmagyaróvár).

In recent decades (1991–2018), the length of the three longest uninterrupted precipitation-free periods typically lasted 8–10 days (40%), but in more than a quarter of cases (27%), these periods lasted for up to two weeks, and in nearly a fifth of them (19%) for more than 2 weeks. These values are higher in all three cases than in the reference period (1961–1990), although the difference is not significant in either case ($p>0.05$).

Our comparative work indicates that the danger of droughts followed by heavy rainfall can reduce the water uptake of soil and increase the potential for runoff and leaching, thereby creating unfavorable conditions for fungal infection of the leaf and root (*Rosenzweig et al*., 2001). The proportion of loss resulting from rainfall-abundance damage (flood, inland water) has increased since the 1970s, which, within Europe, affected Central European countries the most (*EEA*, 2016).

5. Conclusions

In addition to the average values of climatic parameters, the probability, frequency, and severity of their effects on the environment must be taken into consideration when examining changes in the climate system. In the form of statistical evaluation, this knowledge provides more extensive and usable quantified information about the current state of atmospheric conditions affecting our immediate environment.

The results of our studies show an unequivocal warming in the two examined climate cycles (1961–1990; 1991–2018). This is also accompanied not only by the increasing frequency of high or extremely high temperatures, but also by the drastic decrease in the number of low temperatures.

Our results show a change in the length of the three longest uninterrupted precipitation-free periods (days) in the time interval between April and September. We also examined the lengths (days) of the rainy periods immediately preceding and following these precipitation-free periods, the amount (mm) and the average (mm) of precipitation during these time intervals. Although the difference between the two climate cycles was not significant, the combined assessment of quantity and occurrence (i.e., the distribution of precipitation-free days) shows less frequent but more intense precipitation. In addition, the lengths of the longest precipitation-free periods in the April–September interval has been extended significantly, which contributes to severe drought and water scarcity. Based on our results and the work of *Szász* (2002), the long-term lack of precipitation accompanied by extremely high temperatures further amplifies its adverse effect. In addition to rising temperatures, water-stress and unpredictable heavy rainfall events, the disappearance of winter frosts also result in a rearrangement of the ecosystem. The changing environmental conditions affects the plant-production-based economic system seriously, which forces the agro-economic actors find their adaptation strategies.

Our task in the future is to mitigate the anthropogenic impacts that amplify climate change and to prevent the damage to natural resources. While this process is tried to be got under control, we must be prepared to deal with damages that affect our living conditions, health, food production, economy and also to avoid possible disasters. The greatest problem is the simultaneous occurrence of heat and the drought which greatly affects the livelihood of farmers and the success of their production activities. Therefore, water-saving and water-retaining tillage can help against the adverse effects of climate change.

In addition, there is a need to disseminate and develop tools and methods that can counter extreme effects – such as flooding rains, long precipitation-free periods, heat waves, or even the complete absence of frost – and mitigate their consequences.

Such solutions could be the extension of irrigation systems or the breeding of new stress-tolerant plant varieties, which are costly but can effectively result in a reduction of negative impacts (*Lobell et al*., 2008).

References

Bánáti, D., 2019: Az élelmiszerek jövője. Műszaki, technológiai és gazdasági kihívások a 21. században című konferencia: nemzetközi magyar nyelvű tudományos konferencia: előadások és poszterek összefoglalói. (Eds*: Bíró, I., et al*.) Szegedi Tudományegyetem 16. (In Hungarian)

Bartholy, J., Bozó, L., and *Haszpra, L.*, 2011: Klímaváltozás – 2011. Klímaszcenáriók a Kárpát–medence térségére. Magyar Tudományos Akadémia és az Eötvös Loránd Tudományegyetem Meteorológiai Tanszéke, Budapest. (In Hungarian)

Bognár, R. and *Erdélyi, D.*, 2018: Az éghajlatváltozás kihívásai a GDP alapú gazdasági teljesítmény-értékelés számára Magyarország példáján bemutatva. *Studia Mundi–Economica 5*(4), 3–13. (In Hungarian) https://doi.org/10.18531/Studia.Mundi.2018.05.04.3-13

Bokhorst, S., Bjerke, J.W., Bowles, F.W., Melillo, J., Callaghan, T.V., and *Phoenix, G.K.*, 2008: Impacts of extreme winter warming in the sub-Arctic: growing season responses of dwarf shrub heathland. *Glob. Change Biology 14*, 2603–2612. https://doi.org/10.1111/j.1365-2486.2008.01689.x

Boubacar, I., 2010: The effects of drought on crop yields and yield variability in Sahel. Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010 (No. 1370-2016-108718).

Bozó, L., Horváth, L., Láng, I., and *Vári, A.*, 2010: Környezeti jövőkép Környezet- és klímabiztonság. Magyar Tudományos Akadémia, Budapest. (In Hungarian)

Buzási, A., Pálvölgyi, T. and *Szalmáné Csete M.*, 2018: K-faktor: Klíma, gazdaság, társadalom. BME Gazdaság-és Társadalomtudományi Kar Környezetgazdaságtan Tanszék, Budapest. (In Hungarian)

Cantos, J.O., Serrano-Notivoli R., Miró J., and *Meseguer-Ruiz, O.*, 2019: Tropical nights on the Spanish Mediterranean coast, 1950-2014. *Climate Res. 78*, 225–236. https://doi.org/10.3354/cr01569

Challinor, A.J., Simelton, E.S., Fraser, E.D., Hemming, D., and *Collins, M.*, 2010: Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China. *Environ. Res. Lett. 5*(3), 034012. https://doi.org/10.1088/1748-9326/5/3/034012

Dunkel, Z., Bozó, L. and *Geresdi, I.*, 2018: Az éghajlatváltozás hatására fellépő környezeti változások és természeti veszélyek. *Földrajzi Közlemények 142*, 261–271. (In Hungarian) https://doi.org/10.32643/fk.142.4.1

Dunkerley, D., 2015: Intra-event intermittency of rainfall: an analysis of the metrics of rain and no-rain periods. *Hydrol. Proces. 29*, 3294–3305. https://doi.org/10.1002/hyp.10454

EEA, 2016: Floodplain management: reducing flood risks and restoring healthy ecosystems. https://www.eea.europa.eu/highlights/floodplain-management-reducing-flood-risks.

EEA, 2017: Climate change, impacts and vulnerability in Europe 2016. An indicator-based report. European Environment Agency, 71.; 76..

EEA. 2018: Global and European temperature, https://www.eea.european.eu/data-and-maps/indicators/global-and-european-temperature-9/assessment

Faragó, T., Führer, E., Iványi, Z., Járó, Z., Jászay, T., and *Práger, T.*, 1990: Az éghajlat változékonysága és változása: okok, folyamatok, regionális hatásaik különös tekintettel a lehetséges társadalmi-gazdasági következményekre. Környezetvédelmi és Területfejlesztési Minisztérium, Országos Meteorológiai Szolgálat. Budapest. (In Hungarian)

Feurdean, A., Vannière, B., Finsinger, W., Warren, D., Connor, S. C., Forrest, M., Liakka, J., Panait, A., Werner, C., Andricˇ, M., Bobek, P., Carter, A. V., Davis, B., Diaconu A-C., Dietzel, E., Feeser, I., Florescu, G., Gałka, M., Giesecke, T., Jahns, S., Jamrichová, E., Kajukało, K., Kaplan, J., Karpinska-Kołaczek, M., Kołaczek, P., Kuneš, P., Kupriyanov, D., Lamentowicz, M., Lemmen, C., Magyari, E. K., Marcisz, K., Marinova, E., Niamir, A., Novenko, E., Obremska, E., P˛edziszewska, A., Pfeiffer, M., Poska, A., Rösch, M., Słowinski , M., Stan ˙ cikait ˇ e˙, M., Szal, M., Swi˛eta-Musznicka ´, J., Tan¸tauˇ I., Theuerkauf, M., Tonkov, S., Valkó, O., Vassiljev, J., Veski, S., Vincze, I., Wacnik, A., Wiethold, J., and *Hickler T.*, 2020: Fire hazard modulation by long-term dynamics in land cover and dominant forest type in eastern and central Europe. *Biogeosci. 17*, 1213–1230. https://doi.org/10.5194/bg-17-1213-2020

Flohn, H., 1980: Possible climatic consequences of a man-made global warming. IIASA, RR80-30.

Gáborjányi, R., Barna, B., Basky, Z., Benedek, P., Holb, I., Kazinczi, G., and *Kövics, G.*, 2007: A globális éghajlatváltozás várható hatásai a növényvédelemben. Szaktudás Ház Kiadó, 204–206. (In Hungarian)

Gelybó, G., Tóth, E., Farkas, C., Horel, Á., Kása, I., and *Bakacsi, Z.*, 2018: Potential impacts of climate change on soil properties. Agrokémia és Talajtan 67, 121–141. https://doi.org/10.1556/0088.2018.67.1.9

Gosic, M., and *Trajkovic, S.*, 2013: Analysis of precipitation and drought data in Serbia over the period 1980–2010. *J. Hydrology 494*, 32–42. https://doi.org/10.1016/j.jhydrol.2013.04.044

Harnos, Zs. and *Csete, L.* (szerk.) 2008: Klímaváltozás: környezet - kockázat – társadalom, Szaktudás Kiadó Ház, Budapest. (In Hungarian)

Horváth, J. and *Komarek, L.*, 2016: A világ mezőgazdaságának fejlődési tendenciái. Hódmezővásárhely, Innovariant Nyomdaipari Kft, NKA. 19. (In Hungarian)

Illy, T., Sábitz, J., and *Szépszó, G.*, 2015: Az ALADIN-Climate modellkísérletek eredményeinek validációja. RCMTéR (EEA-C13-10) projekt beszámoló, Országos Meteorológiai Szolgálat, Budapest, 19. (In Hungarian)

Ferguson, J.C., Tarara J.M., Mills, L.J., Grove, G.G., and *Keller, M.*, 2011: Dynamic thermal time model of cold hardiness for dormant grapevine buds. *Ann. Botany 107*, 389–396. https://doi.org/10.1093/aob/mcq263

Jolánkai, M., Tarnawa, A., Horvath, C., Nyárai, F.H., and *Kassai, K.*, 2016: Impact of climaticfactors on yield quantity and quality of grain crops. *Időjárás120*, 73–84.

Keller, B., Jung, A., Nagy, G.M., Dénes, F., Péterfalvi, N., Szalay, K.D., 2017: Hiperspektrális távérzékelés alkalmazási lehetőségeinek bemutatása egy málna ültetvény példáján keresztül. A Kutatói utánpótlást elősegítő program a Nemzeti Agrárkutatási és Innovációs Központban a Földművelésügyi Minisztérium támogatásával valósul meg. fiatalkutato. naik. hu, 63.

Łabędzki, L.Ł. and *Bąk, B.*, 2017: Impact of meteorological drought on crop water deficit and crop yield reduction in Polish agriculture. *J. Water Land Develop. 34*, 181–190. https://doi.org/10.1515/jwld-2017-0052

Lábó, E., Zsebeházi, G., and *Lakatos, M.*, 2018: Az IPCC 1,5 fokos globális hőmérséklet-emelkedést értékelő Tematikus Jelentésének margójára. OMSZ. https://www.met.hu/ismeret-tar/erdekessegek_tanulmanyok/index.php?id=2334&hir=Az_IPCC_1,5_fokos_globalis_homers eklet-emelkedest_ertekelo_Tematikus_Jelentesenek_margojara (Donwloaded: 2020. 08. 25.) (In Hungarian)

Landsberg, H.E., 1979: Climatic fluctuations. In ”Yearbook. Science and Technology”, McGraw Hill.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, R.L., 2008: Prioritizing climate change adaptation needs for food security in 2030. *Science 319*(5863), 607–610. https://doi.org/10.1126/science.1152339

Lun, D., Fischer, S., Viglione, A., and *Blöschl, G.* 2020: Detecting flood-rich and flood-poor periods in annual peak discharges across Europe. *Water Resour. Res. 56*(7), e2019WR026575. https://doi.org/10.1029/2019WR026575

Maracchi, G., 2000: Agricultural drought—A practical approach to definition, assessment and mitigation strategies. In (Eds. *J.V. Vogt*, and *F. Somma*) Drought and drought mitigation in Europe. Advances in natural and technological hazards research14, 63–78. https://doi.org/10.1007/978-94-015-9472-1_5

Mcleman, R. and *Smit, B.* 2006: Vulnerability to climate change hazards and risks: crop and flood insurance. *Canadian Geographer/Le Géographe canadien*, *50*, 217–226. https://doi.org/10.1111/j.0008-3658.2006.00136.x

Mika, J., 2018: A klímaváltozás világléptékű, európai és hazai újdonságai. Természet-, műszaki-és gazdaságtudományok alkalmazása nemzetközi konferencia, 8–18. (In Hungarian)

Németh, N., 2019: A magyar mezőgazdálkodók éghajlatváltozáshoz való alkalmazkodóképességének vizsgálata Győr-Moson-Sopron és Vas megyékben (Doctoral dissertation, nyme). (In Hungarian)

Nordhaus, W., 2019: Climate change: The ultimate challenge for Economics. *Amer. Economic Rev. 109*, 1991–2014. https://doi.org/10.1257/aer.109.6.1991

Pálvölgyi, T., Czira, T., Bartholy, J., and *Pongrácz, R.* 2011: Éghajlati sérülékenység a hazai kistérségek szintjén. In: (Eds.: *Bartholy J., Bozó L., Haszpra L.*) : Klímaváltozás – 2011. Klímaszcenáriók a Kárpát-medence térségére. MTA, ELTE, Budapest, 236–256. (In Hungarian)

Pinke, Z. and *Lövei, G.L.*, 2017: Increasing temperature cuts back crop yields in Hungary over the last 90 years. *Glob. Change Biol. 23*, 5426–5435. https://doi.org/10.1111/gcb.13808

Rosenzweig, C., Iglesias, A., Yang, X.B., Epstein, P.R., and *Chivian, E.* 2001: Climate change and extreme weather events; implications for food production, plant diseases, and pests. *Glob. Change Human Health 2*(2), 90–104. https://doi.org/10.1023/A:1015086831467

Ryu, S., Han, H.H., Jeong, J.H., Kwon, Y., Han, J.H., Do, G. R., ChoiI, M. and *Lee, H.J.*, 2017: Night temperatures affect fruit coloration and expressions of anthocyanin biosynthetic genes in 'Hongro'apple fruit skins. *Eur. J. Hortic. Sci. 82*, 232–238. https://doi.org/10.17660/eJHS.2017/82.5.2

Sassi, M., Nicotina, L., Pall, P., Stone, D., Hilberts, A., Wehner, M., and *Jewson S.*, 2019: Impact of climate change on European winter and summer flood losses. *Adv. Water Resour. 129*, 165–177. https://doi.org/10.1016/j.advwatres.2019.05.014

Spinoni, J., Naumann, G., Vogt, J., and *Barbosa, P.*, 2015a: European drought climatologies and trends based on a multi-indicator approach. *Glob. Planet. Change 127*, 50–57. https://doi.org/10.1016/j.gloplacha.2015.01.012

Spinoni, J., Szalai, S., Szentimrey, T., Lakatos, M., Bihari, Z., Nagy, A., Németh, A., Kovács, T., Mihic, D,. Dacic, M., Petrovic, P., Krži˘c, A., Hiebl, J., Auer, I., Milkovic, J., Štepánek, P., Zahradnícek, P., Kilar, P., Limanowka, D., Pyrc, R., Cheval, S., Birsan, M. V., Dumitrescu, A., Deak, G., Matei, M., Antolovic, I., Nejedlík, P., Štastný, P., Kajaba, P., Bochnícek, O., Galo, D., Mikulová, K., Nabyvanets, Y., Skrynyk, O., Krakovska, S., Gnatiuk, N., Tolasz, R., Antofie T., and *Jürgen V.*, 2015b: Climate of the Carpathian Region in the period 1961–2010: climatologies and trends of 10 variables. *Int. J. Climatol. 35*, 1322–1341. https://doi.org/10.1002/joc.4059

Szabó, M. and *Fári, M.G.*, 2017: Új egynyári dísznövény nemesítési alapanyag létrehozása mutáns-indukációval és a vegetatív szaporítás lehetőségei, XXIII. Növénynemesítési Tudományos Nap, Szerk.: Veisz Ottó, MTA Agrártudományok Osztálya 71. (In Hungarian)

Szász, G., 2002: Utilization of Climatic Natural Resources in Domestic Crop Production. *Acta Agraria Debreceniensis 9,* 101–106. https://doi.org/10.34101/actaagrar/9/3567

Teixeira, E.I., Fischer, G., Van Velthuizen, H., Walter, C., and *Ewert, F.* 2013: Global hot-spots of heat stress on agricultural crops due to climate change. *Agricult. Forest Meteorol. 170*, 206–215. https://doi.org/10.1016/j.agrformet.2011.09.002

Ummenhofer, *C.C.* and *Meehl*, *G.A.*, 2017: Extreme weather and climate events with ecological relevance: a review. *Philosop. Trans.Roy. Soc. B: Biological Sciences*, 372(1723), 20160135. https://doi.org/10.1098/rstb.2016.0135

Uzzoli, A., 2015: Klímamodellek a társadalmi alkalmazkodásban–A sérülékenységvizsgálatok hazai eredményei és tapasztalatai. 109–126.

WMO, 2019: World Meteorological Organization Statement on the State of the Global Climate in 2019, WMO, ISBN 978-92-62-11248-5

Xie, S. P., Deser, C., Vecchi, G. A., Collins, M., Delworth, T. L., Hall, A., and *Watanabe, M.* 2015: Towards predictive understanding of regional climate change. Nat. Climate Change 5(10), 921-930. https://doi.org/10.1038/nclimate2689