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Long-term development and prediction of climate extremity and heat waves occurrence: Case study for agricultural land

Marta VANÍČKOVÁ, Eva STEHNOVÁ, Hana STŘEDOVÁ

Department of Applied and Landscape Ecology, Mendel University in Brno, Zemědělská 1665/1, 613 00 Brno, Czech Republic; e-mail: hana.stredova@mendelu.cz

Abstract: According to the IPCC it is possible to predict larger weather extremity associated with more frequent occurrence of heat waves. These waves have an impact not only on the health status of the population, on economic, social and environmental spheres, but also on agricultural landscape and production. The paper deals with the issue of climate extremity and addresses mainly the occurrence of characteristic days (tropical, summer, freezing, ice and arctic) and heat waves. The south-eastern Moravia belongs to the warmest regions of the Czech Republic. Since the area is not urban, it is not affected by urban heat islands. Thus, it can be used as a representative area of climate change in terms of weather extremes. Heat wave occurrence and length analysis was performed for the period of 1931–1960 and 1961–2013. In addition, a prospective analysis was carried out for the period of 2021–2100 where the scenario data of the Czech Hydrometeorological Institute were used. Between 1961 and 1990, heat waves appeared from June to September. The prediction for the next two decades shows that heat waves may appear as early as May. Furthermore, the average count of days in heat waves increased from 6.13 days (1961–1990) to 36 days (2071–2100). A statistically significant increase in the annual number of tropical days (from 9 to 20 days) was found in the assessment of characteristic days for the period 1961–2013. A highly conspicuous trend was found in July and a prominent trend was identified in May. A statistically highly significant trend was also observed in the annual number of summer days.

Key words: heat waves, the Czech Republic, South Moravia, characteristic days, climate change

1. Introduction

Wildlife, plants and crops are affected not only by too low temperatures but recently also by extraordinary high temperatures (above their optimum

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limit). In this context, the term heat wave, which is often defined as a very long episode of extraordinary hot weather, is used. However, the term is relative due to climatic conditions of specific location. Therefore, the World Meteorological Organization (WMO) recommends that heat wave be defined as the period during which the daily maximum air temperature in five consecutive days is at least 5 °C higher than the normal average daily maximum for a given period (Heat Wave Duration Index HWDI) (*Frich et al., 2002*).

The Meteorological Dictionary (*Sobíšek et al., 1993*) for climate conditions of Central Europe defines the heat wave as an at least three-day period of summer heat during which the maximum daily air temperature reaches 30 °C or more. The existence of a heat wave in Central Europe is mainly conditioned by the occurrence of tropical air above the mainland.

The more frequent occurrence of heat waves is influenced by climate development and rising greenhouse gas concentrations. According to the predictions of the Intergovernmental Panel on Climate Change (*IPCC, 2013*) more frequent occurrences of heat waves can be expected. These waves will be more intense and there will be longer wave-lengths (*Russo et al., 2014; Mužíková et al., 2011*). Heat waves have a major impact on the health or comfort of the population. They affect also social, ecological and economic systems. Wider impacts of heat waves may include effects on the retail industry, ecosystem services and tourism (*McGregor et al., 2007*). *Patz et al. (2005)* state that heat waves cause considerable human health problems, especially in large cities where effects of the thermal islands are amplified (*Hunt et al., 2016*). The research shows that the warning system contributes to improvement of health of the inhabitants of these cities. *Smith and Woodward (2014)* states that heat waves cause an increase in mortality and diseases in Europe. Mortality analysis during heat waves was carried out by *Kyselý and Huth (2004)* in the Czech Republic.

Negative impacts are also experienced on agricultural landscape and production. For example, *Ciais et al. (2005)* demonstrate crucial influence of heat waves on agriculture and global ecosystems. It is important to develop appropriate strategies to adapt to these changes (*Beniston et al., 2016*). Numerous authors observed that elevated greenhouse gas concentrations and subsequent climate changes could lead to the range expansion of plant diseases and pests in agricultural ecosystems. New diseases or pests of agricultural crops may occur (e.g. *Středa et al., 2013*).

According to the Environmental security conception of the Czech Republic the extreme heat weather is being ranked among the most dangerous natural risk to the human society. There is a need to increase resilience of the society and develop a risk plan to mitigate consequences of these events. However, precise localization and quantification of this phenomenon is required in the first place.

2. Materials and methods

Evaluated characteristics

The article analyses characteristic days and heat waves for the periods of 1931–1960 and 1961–2013. In addition, prospects for years 2021–2100 were established based on climate scenario data.

a) Heat waves (HW)

A heat wave is a multi-day (minimum three-day) summer heat period during which the maximum daily temperature reaches 30 °C or more. Evaluated parameters of HW were as follows:

- Comparison of the average values of three long-term periods 1961 – 1990, 2021–2050 and 2071–2100 (Fig. 1) – namely:
    - Monthly and annual average number of days in HW,
    - Average length of HW,
    - Average temperature of HW.
- Trend analysis of monthly and annual number of days in HW for the period of 1961–2013 (Fig. 2).

b) Characteristic days

Typical days in climatological analysis are **tropical, summer, ice, freezing and arctic days.**

Tropical day (TD): maximum temperature (Tmax) of the air reaches 30 °C or more.

Summer day (SD): Tmax reaches 25 °C or more.
Freezing day (FD): minimum air temperature is lower than 0 °C.
Ice day (ID): Tmax reaches 0 °C or less.
Arctic Day (AD): Tmax does not exceed –10 °C.
Evaluated parameters of the characteristic days were as follow:

- Comparison of the monthly and annual average number of characteristic days of three long-term periods 1961–1990, 2021–2050 and 2071–2100 plus retrospective comparison with average annual number of the days in 1931–1960 (Fig. 3).
- Trend analysis of monthly and annual number of characteristic days for the period of 1961–2013 (Figs. 4 to 8).

Employed statistical method

To identify trends within time series the Mann-Kendall test was used. This method is widely used in scientific disciplines dealing with the environment. If P (rate of signification) is smaller than 0.01 there is a highly significant linear trend, and if P is smaller than 0.05 there is a significant linear trend.

Used climate data

a) 1931–1960:
As there was no data from Boeclav station from the period 1931–1960 so that the data series from the nearest station (Strážnice) were used to illustrate the respective characteristics in this period. Average long-term climatic characteristics for this period were derived from the publication Agroclimatic conditions of CSSR (*Kurpelová et al., 1975*).

b) 1961–2013:
Data for this period were obtained from the Technical Data Series (TDS) in a grid network of 10 km. TDS is based on data from the climatological station network of the Czech Hydrometeorological Institute. Database was created in grid points of outputs of the regional climatic model ALADIN-Climate/CZ. Prior to the TDS calculation, the input data were subjected to data quality control using the ProClimDB software (*Štěpánek, 2007*). Once errors were corrected, the series were homogenized. Missing daily values were also added for each climatological station using geostatistical methods.

The TDS calculation itself is based on the IDW method (an interpolation method based on inverse distance) where data of the surrounding climatological stations are first standardized at the altitude of the point for which the TDS is calculated (*Štěpánek et al., 2008; Kyselý et al., 2008*).

c) 2021–2100:

In order to capture the future climate trend, scenario data were created at the Czech Hydrometeorological Institute. The scenario data were created by integration of the regional climate model ALADIN-Climate/CZ within the CECILIA international project. As part of this project, climatic conditions for Central Europe were simulated using ALADIN-Climate/CZ with a resolution of 10 km. The simulation was carried out for two 30-year periods (2021–2050 and 2071–2100) using the A1B emission scenario (according to IPPC). Scenario data correction (2021–2050 and 2071–2100) was then performed according to the Déqué method (*Déqué, 2007*). The method is based on correction of a meteorological element by comparing individual percentiles of two data sets. The creation of grids and all data processing including the analysis of future climate was carried out by the ProClimDB software used for processing of climatic data (*Štěpánek, 2007*).

Area of interest

The analysis itself was carried out for the reference grid point Boeclav at an altitude of 176 m above sea level and locality Strážnice (located approximately 30 km away from the reference point). Climatological station Strážnice was selected as the nearest station with climatological record for the period of 1931–1960.

Almost the whole territory of Břeclav has a lowland character. The landscape character of Břeclav region is characterized by a slightly indented terrain up to a flat relief with an altitude from 155 to 185 m above sea level. The relief around Strážnice is mostly flat.

The sites of Břeclav and Strážnice were further evaluated in terms of the international widely used Köppen-Geiger climatic classification. The classification is based on temperature and rain regime and its effect on vegetation. It was found that most of the territory of the Czech Republic including the analysed sites belong to the (Dfb) zones of moderate cold climate with a uniform distribution of precipitation during a year with mild summer (*Peel* *et al, 2007*).

The basic climatic characteristics of these sites according to *Tolasz (2007)* are:

Břeclav

- the average air temperature is 9–10 ° C;
- average annual precipitation total is 500–550 mm;

Strážnice

- the average air temperature is 9–10 °C;
- average annual precipitation total is 450–500 mm.

3. Results and discussion

Evaluation of HW trends

Long-term HW analysis is shown in Fig. 1. In the period of 1961–1990 heat waves occurred between June and September. However, the prediction for the two subsequent thirty-year periods expects their occurrence as early as in May. The prediction also suggests an increase in the average annual number of days in heat waves which will increase from 6.1 in the period of

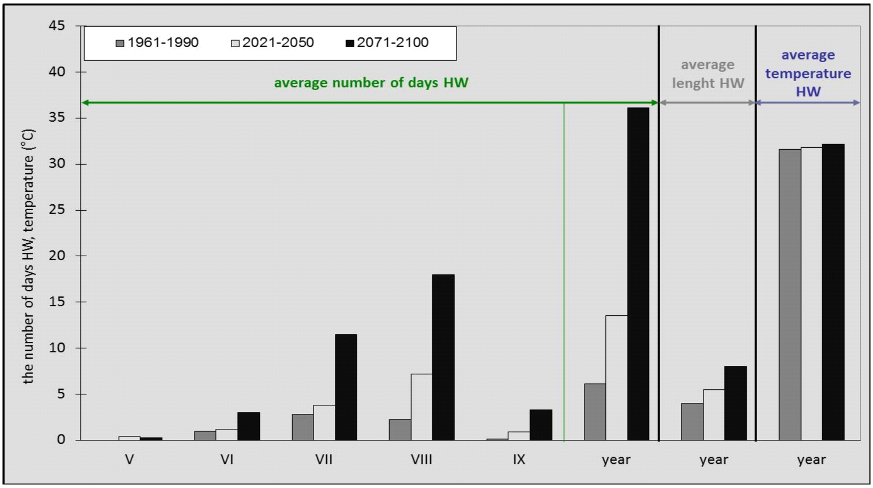

Fig. 1. Parameters of HW in three long-term seasons.

1961–1990 through 13.5 in 2021–2050 to 36 in 2071–2100. The prediction also sees an increase in the average wavelength from 4 through 5.5 to 8 days. This phenomenon will be amplified by a slight increase in the average heat wave temperature (from 31.6 through 31.8 to 32.2 °C).

A detailed analysis of the trend of the number of days in heat waves in individual months and years in the context of average daily temperatures during the period 1961–2013 is given in Fig. 2. Heat waves usually occur between June and August with a peak in July (except for 2005 with one three-day heat wave in May and 1973 with a four-day heat wave in September). While the air temperature increase is statistically highly significant in pretty much all months (May to August) and annually as well, the number of heat wave days does not increases significantly at all.

According to *Hupfer et al. (2009)* frequency, intensity and duration of heat waves did not increase generally during the 20th century. But in the 21st century, especially in the second half, the situation will alter dramatically.

Characteristic days evaluation

Fig. 3 compares the total number of characteristic days in individual months and years in the period of 1961–1990 and two subsequent thirty-year periods. Tropical days occur from May to September with a maximum in July and August, while summer days occur between March and October again with July and August maxima. Freezing days were recorded from October to April (in the period of 1961–1990 unique occurrence was also observed in May). Ice days occur between November and March, however the period of 2071–2100 sees their occurrence only until February. Arctic days occur between January and February in the period of 1961–1990 (14 days in total), the period of 2021–2050 should see only six Arctic days in January.

A detailed long-term analysis of the number of characteristic days in individual months and years including the evaluation of the trend for the period 1961–2013 is presented in Figs. 4 to 8 and in Tables 1 to 5. The annual count of tropical days statistically significantly increases from 9 to 20 days. Their increase is significant in July (from 3.4 to 8.4). *Středová et al. (2010)* found out statistical significant increase of number of tropical days for the period of 1987 to 2008 for the urban area of Brno city. Nevertheless, this statistical increase was not detected for the suburban Brno landscape.

The annual count of summer days also shows a statistically significant increase as their number increases from 53 to 71. Significant increase in the count of summer days was seen in July and August (increase from 16 to 21 or 15 to 21 respectively). Annual and monthly number of ice, freezing and arctic days does not show any significant change.

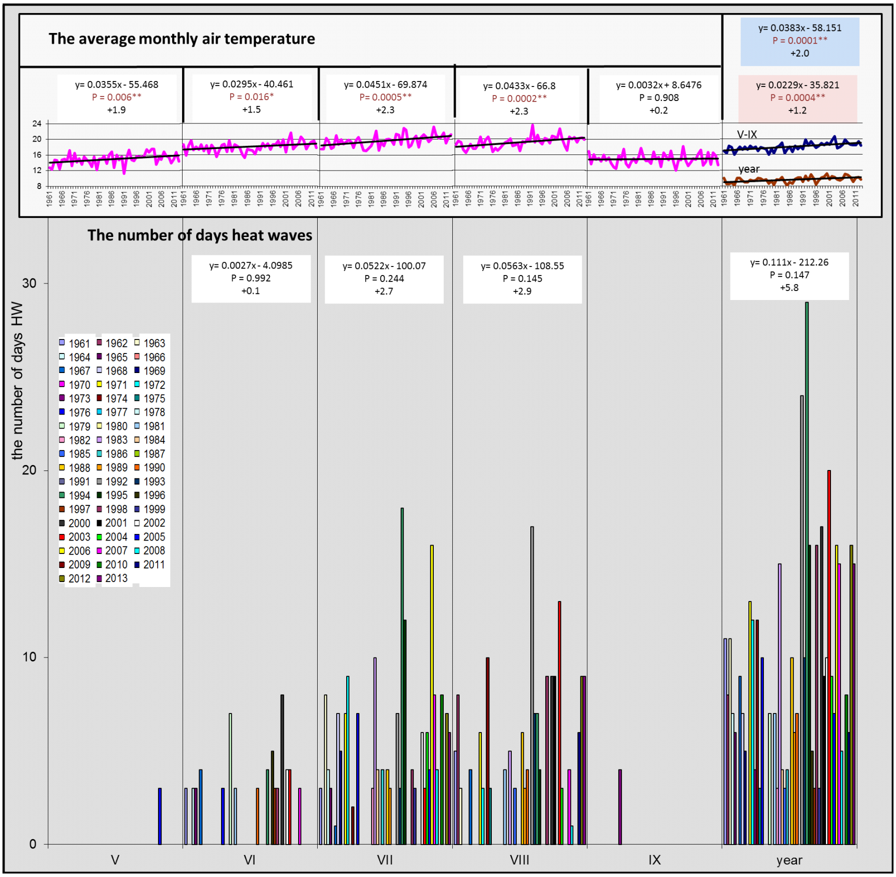

Fig. 2. Monthly and annual number of days in HW along with air temperature course, 1961–2013; legend to inserted tables is as follows:

Statistical significance	
P value of Mann-Kendall test	P < 0.01 **
	P < 0.05 *
Change in the prospective units	(°C, days)

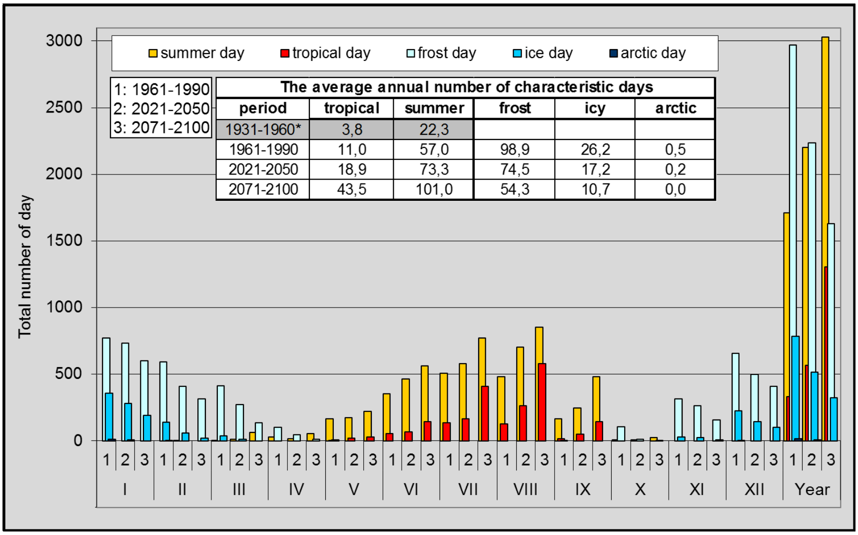

Fig. 3. Total monthly and annual amount of characteristic days in three (or four) long-term seasons (I–XII = January–December).

Table 1: Evaluation of monthly and annual trend in number of tropical days for the period of 1961 to 2013.

Period	P value of Mann-Kendall test	Shift 1961–2013 (days)
IV	0.109	0
V	0.055	+0.7
VI	0.294	+2.0
VII	0.027*	+5.1
VIII	0.104	+3.5
IX	0.845	−0.2
YEAR	0.007**	+11.2

Table 2: Evaluation of monthly and annual trend in number of summer days for the period of 1961 to 2013.

Period	P value of Mann-Kendall test	Shift 1961–2013 (days)
IV	0.036*	0.4
V	0.203	+2.0
VI	0.154	+3.3
VII	0.034*	+5.5
VIII	0.010*	+6.1
IX	0.871	+0.3
X	0.364	+0.3
YEAR	0.005**	+17.7

Table 3. Evaluation of monthly and annual trend in number of frost days for the period of 1961 to 2013.

Period	P value of Mann-Kendall test	Shift 1961–2013 (days)
I	0.113	−4.3
II	0.896	+0.8
III	0.853	−0.8
IV	0.932	+0.2
IX	0.281	−0.2
X	0.792	−0.5
XI	0.627	−0.5
XII	0.140	−3.5
YEAR	0.322	−8.7

Table 4. Evaluation of monthly and annual trend in number of ice days for the period of 1961 to 2013.

Period	P value of Mann-Kendall test	Shift 1961–2013 (days)
I	0.544	−2.7
II	0.695	+0.6
III	0.409	−0.7
XI	0.750	+0.5
XII	0.871	−1.0
YEAR	0.920	−3.3

Table 5. Evaluation of monthly and annual trend in number of arctic days for the period of 1961–2013.

Period	P value of Mann-Kendall test	Shift 1961–2013 (days)
XII	0.709	0.0
I	0.441	−0.1
II	0.922	0.0
YEAR	0.393	−0.1

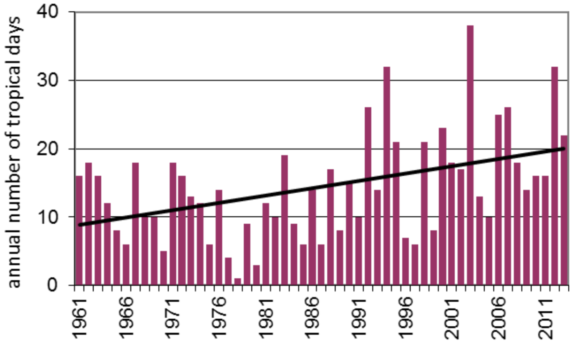

Fig. 4. Annual number of tropical days and its trend line for the period of 1961 to 2013.

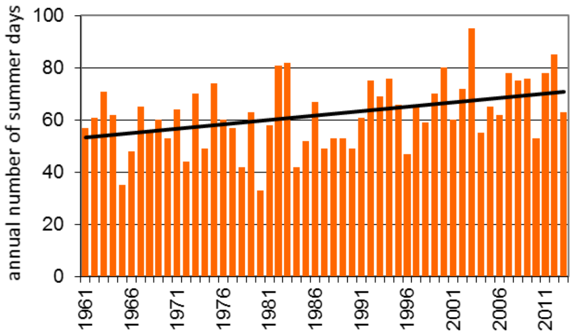

Fig. 5. Annual number of summer days and its trend line for the period of 1961 to 2013.

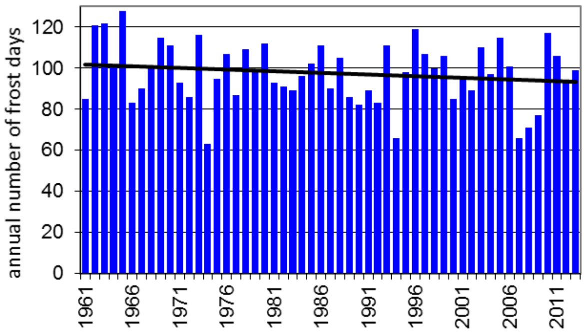

Fig. 6 Annual number of frost days and its trend line for the period of 1961 to 2013.

4. Conclusions

The analysis of heat waves shows that in the future there will be an earlier occurrence of heat waves starting in May. In the future, there will be also an increase in the average annual count of heat wave days which will be amplified by a slight increase in the average heat wave temperature (from 31.6 °C to 32.2 °C). Air temperatures during the period of 1961–2013 in all months (May to August) revealed a statistically highly significant increase. However, the number of heat wave days grew significantly only in the yearly sum.

Based on predictions, it is suggested that the annual number of tropical and summer days will increase in the future. The analysis revealed that during the period of 1961–2013 there was a statistically significant increase

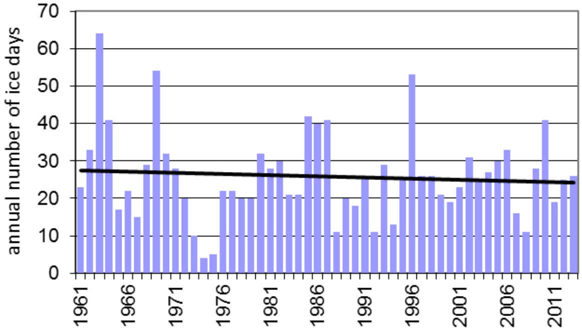

Fig. 7. Annual number of ice days and its trend line for the period of 1961 to 2013.

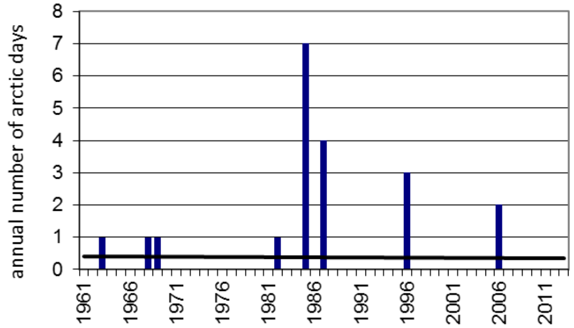

Fig. 8. Annual number of arctic days and its trend line for the period of 1961 to 2013.

in tropical days (annually and in July) and summer days (annually and in July and August). Changes in the count of ice, freezing and arctic days do not show statistically significant trends.

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