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HEAT WAVES. CONCEPT, DEFINITION AND METHODS USED TO DETECT

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ABSTRACT. - Heat waves. Concepts, definition and methods used to detect. Heat waves have been assessed, as the most dangerous weather events in the United States and in Australia, due to its major impact on human body. Consequently, detailed analyses is needed, both at global as well as at regional or local scales. Due to the high number of definitions and methods used to detect heat waves in the international scientific literature, in this study, we propose a review of the concept, the methods and data used to detect. We also made a brief comparison between two methods: 95th percentile-based method and 35ºC fixed threshold method. As main result, we found that the 95th percentile method is more appropriate as it allows detection of the heat waves all around the year and for each weather stations under study, while the fixed threshold method is very sensitive to location of the weather stations and season.

Key words: heat waves, threshold, detection methods, Romania

Introduction

In the general context of climate change, it is considered that extreme temperatures will be some of the most affected climatic parameters. The changes will imply frequency, intensity, and persistence. Among the temperature-related climatic hazard, heat waves (HWs) play an important role because they act, usually at large or very large spatial scale and have a major impact on environment, society, and economy.

Recently, many researchers focused on HWs, conducting studies on climatic features of the HWs (Diffenbaugh and Scherer, 2011, Coumou et al., 2013), on perception of the communities prone to such extreme weather events (Hansen et al., 2012), on the impact of HWs on tourism (Belén Gómez-Martín et al., 2013), or on their biometeorological impact (Xu et al., 2013, Peterson et al., 2013).

In Romania, most of the papers were developed base on study cases and not to the climatology and the impact of the phenomenon. The most consistent study considered HWs in the larger context of climate changes in Romania (Busuioc et al., 2010).

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The main aim of this study is to present in details the concept and the methods generally used to detect HWs worldwide.

We decided to conduct such a research because of two main reasons:

a. The first one is due to the major impact that HWs have on human health and well-being: HWs have been assessed, in a recent paper (Peterson et al., 2013), as the most dangerous weather events (the number one weather-related killer) in the United States; also, it was considered by the Australian Bureau of Meteorology that they have taken more Australian lives than any other natural hazard in the past 200 years.

b. The second reason was a scientific one related to definition and detection methods of the HWs: there are a lot of definitions of the heat waves worldwide as well as many methods to detect them. The decision to use one or another method can be quite difficult and a detailed analysis should be previously done. Moreover, in Romania there is not a clear definition of the HWs, or a specific method to detect them.

2. What do we talk about?

In this chapter we made a literature review on what exactly are the HWs? From the multitude of definitions present in different scientific papers and other sources, for this study only few were retained:

- World Meteorological Organization definition of a HW is "when the *daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1961-1990* (www.metoffice.gov.uk);
- Metoffice considers that for the UK, a HW as an *extended period of hot weather relative to the expected conditions of the area at that time of year*. The **Heat-health watch system** comprises four levels of response based upon threshold maximum daytime and minimum night-time temperatures. These thresholds vary by region, but an average threshold temperature is *30°C by day and 15 °C overnight for* a*t least two consecutive days* (www.metoffice.gov.uk);
- In Canada, Montreal Public Health Board (MPHB) proposed an operational definition based on a daytime high of 30°C (*T*max) and night-time low of 22°C (*T*min) for 3 consecutive days (Drouin et al. 2005, Viscovi et al., 2005);
- HWs are usually defined as occurring when temperatures exceed both daytime high and night time low thresholds (Robinson 2001, Vescovi et al., 2005);
- Conducting a study on changes in HWs in the Eastern Mediterranean, Kuglitsch et al. (2010) considered a HW as *a period of three or more consecutive hot days and nights not interrupted by more than one non-hot day or night* (a hot day or night is defined as a day/night when the daily TX/TN exceeds the long-term (1969–1998) daily 95th percentile within the June–September season);

• HWs are typically defined as *events exceeding specified temperature thresholds over some minimum number of days*. Chosen thresholds may be statistical or absolute and in the case of the latter are geographically and sector dependent (Peterson et al., 2013).

• According to ABC news, in Australia, a heat wave is defined by *three or more days of unusually high maximum and minimum temperatures* in any area;

• English dictionary specify about a HW that it is *a period of unusually hot weather/a continuous spell of abnormally hot weather/a period of abnormally hot weather;*

As it can be easily observed, there are numerous definitions and some of them are quite ambiguous. Thus, they are considered *days of unusually high maximum and minimum temperatures,* or *a period of unusually hot weather,* or *a continuous spell of abnormally hot weather,* or *a period of abnormally hot weather*. Regarding the duration of HWs, one can notice that there is also a diversity in the minimum number of consecutive or inconsecutive days or nights from definition to definition. Usually the minimum duration vary from two consecutive days to five consecutive days.

As a synthesis, almost all of the definitions consider a threshold and a minimum number of consecutive days when the specified threshold is exceeded, but it's up to the author's decision which of them chooses.

3. Data and methods

3.1. Data used in HWs detection

In general, most of the authors used daily maximum temperature data in order to detect HWs. There are also some authors who employ maximum and minimum daily data (Kuglitsch et al. (2010)), but in this situations, the number of HWs diminishes very much.

Robust analysis of these events over time requires daily maximum and minimum temperature data from stations with records of sufficient length, quality, completeness, and temporal homogeneity. Homogeneity of the daily temperature record is an especially difficult challenge because of stations experiencing varying degrees of change over time in location, instrumentation, observing practices, and site conditions (Peterson et al., 2013).

In this paper, for the study case, we used daily blend data series available for 8 weather stations in Romania from ECA&D project database (Klain Tank et al., 2002).

3.2. Methods to detect HWs

The main issue in HWs studies is how and what thresholds do we use. Chosen thresholds may be statistical or absolute and in the case of the latter are geographically and sector dependent (Peterson et al., 2013). Thus, the methods can be divided into two main classes:

a. Methods based on fixed thresholds;

b. Methods based on station-related thresholds. In this class, depending on the threshold value considered, there are percentile-based methods (percentile 90 or 95) and average-based methods (average maximum temperature of the day is exceeded by 5°C or by 3°C).

a. In case of ***methods based on fixed thresholds***, the detection is very simple and consists in comparing the daily maximum (and minimum, in the situations when it is consider) temperature to the given threshold values. The main problem with these fixed thresholds (which can be arbitrary chosen) is that they are very sensitive to location change and to the period of the year. Thus, in case of choosing a threshold of 35/37 °C (the minimum values for which, the National Meteorological Administration in Romania releases special warnings - yellow code for heat), it is almost sure that for most weather stations in Romania, the HWs would be specific only during summer time and they are completely excluded during winter, late autumn and early spring. Also, some stations would record many HWs while others could have no HWs during the whole period considered.

Under these circumstances, some situations could occur such as an important warming during winter when a thick snow layer is present; the water will be rapidly released into the rivers and rapid high floods could be generated. And no warning can be released according to the colour code.

Otherwise, when a much lower fix threshold is chosen, there is a risk to detect too many cases with HWs. Under these circumstances, choosing one or another threshold implies to be very cautious and to know very well the area under study.

b. In case of ***methods based on station-related thresholds*** the situation changes as these methods have as main advantage that they are site-independent. For the percentile-based methods, the considered percentile (usually P95) is calculated for each day of the year, from January, 1 to December, 31. It can be calculated based on the entire period considered or based on a reference period (1981-2010, which is the latest reference period recommended by WMO to be used in climatic studies). Both percentile and average values can be calculated by using Microsoft Excel software through the pre-defined functions PERCENTILE and AVERAGE (table 1).

After that, the maximum temperature of each day in the data range is compared to the 95^{th} percentile values for the same day of the year and if the temperature of the day in a specific year is higher than the percentile value, then that day can be potentially part of a HW. A HW occurs when the consecutive number of days that have threshold condition is at least equal to the established minimum length of a HW, which varies from author to author, usually between 2 and 5.

Table 1. Model to calculate the daily percentile and the daily average

Day of the year	1961	1962	1963	.....	2012	2013	95th Per-centile	Average
	Maximum temperature (°C)							
January, 1	3.4	2.6	1.9	.....	4	-1.3	7.4	0.8
January, 2	5.3	4.9	1.2	.....	2.9	-0.9	6.6	0.9
January, 3	9	3.2	0.8	.....	4.6	-2.5	5.5	0.7
......	.....	.....	.....	.....	.....	.....	.....	.....
July, 10	22.7	23	24.1	.....	31.2	26.6	31.2	24.9
July, 11	25.1	27	27	.....	32	26.1	31.8	25.0
July, 12	26.5	25.7	27.5	.....	27	23.6	30.5	25.1
.....	.....	.....	.....	.....	.....	.....	.....	.....
December, 29	3.7	-5.7	0.1	.....	-1.6	5.2	11.8	2.1
December, 30	4.1	0.2	0.6	.....	-0.4	7.2	9.1	1.0
December, 31	1.8	2.4	-0.2	.....	-1.6	8.1	11.8	2.1

An example of detecting a HW is presented below (Table 2). As it can be seen, the heat wave in the given case lasted from 5th of August to 10th of August (six days).

Table 2. Model of detecting a heat wave based on the 95th percentile method at Cluj-Napoca Weather Station

Date in the range	Maximum temperature	Day of the year	95th percen-tile value	Test*	Heat wave
8/2/2013	29.0	Aug, 2	31.88	0	No
8/3/2013	32.6	Aug, 3	32.60	1	No
8/4/2013	31.1	Aug, 4	32.28	0	No
8/5/2013	**32.6**	**Aug, 5**	**32.36**	**1**	**Yes**
8/6/2013	**33.1**	**Aug, 6**	**31.90**	**1**	**Yes**
8/7/2013	**33.9**	**Aug, 7**	**32.58**	**1**	**Yes**
8/8/2013	**35.4**	**Aug, 8**	**32.64**	**1**	**Yes**
8/9/2013	**36.4**	**Aug, 9**	**32.18**	**1**	**Yes**
8/10/2013	**33.2**	**Aug, 10**	**32.78**	**1**	**Yes**
8/11/2013	27.1	Aug, 11	30.90	0	No
8/12/2013	29.0	Aug, 12	29.90	0	No

Note: 1 is for days when the maximum temperature exceeds the 95th percentile value of the day; 0 is for days when the maximum temperature is lower than the 95th percentile value of the day.

In case of average-based methods, the procedure is similar, but the columns *95th percentile value* in Table 2 should be replaced by the *Average +5°C* or by *Average +3°C* columns.

To compare the results of the two types of methods, below there are the results of HWs detected based on the 95th percentile method and on the 35°C fixed threshold over the period 1961-2013 (Table 3). The number of HWs is similar in stations with the same local factors in case of station-related threshold (P95), while in case of the fixed threshold, there are important discrepancies between the stations.

Table 3. Number of heat waves based on Station-related threshold methods and on fixed threshold over the period 1961-2013

Weather stations	WMO code	Number of heat waves based on		Altitude
		P 95	35°C	
Arad	15116	136	5	108.0
Bacău	15150	115	9	185.3
Bucureşti Băneasa	15420	134	28	91.0
Călăraşi	15460	113	45	19.9
Cluj-Napoca	15120	124	2	410.4
Constanţa	15480	89	0	14.0
Sulina	15360	108	3	3.0
Vf. Omu	15280	126	0	2505.1
Total		**2382**	**331**	

Conclusions

After a detailed literature review, the thresholds and duration conditions of HWs vary around the world, and at the time of preparing this paper there is not an universally accepted definition. Under these circumstances it is the authors' decision if they use one or another thresholds or methods. However, they should be very cautious because choosing a less flexible method could lead to unreal achievements.

Based on our analysis, the 95th percentile-based method seems to be the most appropriate because it gives a reasonable number of HWs, it allows comparison between different weather stations in the same region or in different regions and it identifies heat waves all over the year, not only in summertime.

Otherwise, the fixed threshold-based method (35.0 °C) is very sensitive to local factors (altitude is the most important of them), does not allow comparison between different stations even though they are located very closed one to the other; the threshold chosen (35.0 °C) does not fit very well to Romanian territory because it is too high and there are regions in the country which could not be alerted even though the temperature are much higher compared to normal values.

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