CHANGES IN FREQUENCY, PERSISTENCE AND INTENSITY OF EXTREME HIGH-TEMPERATURE EVENTS IN THE ROMANIAN PLAIN

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ABSTRACT. – Changes in frequency, persistence and intensity of extreme high-temperature events in the Romanian Plain. Recent summer heat waves (2003, 2010) had a strong socio-economic impact in different parts of the continent by means of crop shortfalls and forest fires. Sustained hot days became more frequent in the recent decades in many European regions, affecting human health and leading to additional deaths. This signal has been outlined in many studies conducted in Romania, suggesting that the southern region of Romania is particularly subject to large temperature increase. This work investigates the changing annual and seasonal heat waves at regional scale of the Romanian Plain, over period 1961-2014. Daily maximum temperature recorded at six weather stations available from the ECA&D project (European Climate Assessment and Datasets) were analyzed. The changes in the seasonal frequency, duration and intensity of heat waves were studied using the Mann-Kendall nonparametric trend test, as recommended by the scientific expert team on climate change detection. The likelyhood of higher maximum temperatures rise, particularly after the mid 1980s, and the changes in the upper tail of the probability density functions of these temperatures, within the extreme domain (beyond the 95% percentile level), explain the persistence and intensity of heat waves. The upward trends are dominant most of the year, and many of the calculated decadal slopes were found statistically significant (relative to the 5% level), proving an ongoing and strong warming all over the region. Our findings are in good agreement with several recent studies carried out at European and national scale and pledge for further scientific analyses i.e. heat stress impact on public health and agriculture.

Keywords: heat waves, 95% percentile level, frequency, persistence, intensity, Romanian Plain region.

1. INTRODUCTION

Events of general process of heating signaled the end of the twentieth century and the beginning of the XXI century, accompanied by lower rainfall and increased thermal contrasts and pluviometric, with drastic changes in the frequency and intensity of production regime of extreme weather events, are the most pronounced features in the general context of the actual climate change at global scale. Geographic area of the Romanian Plain region experiencies these climate events observed especially after 1984 and 1985, which enhances the high

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vulnerability of the environment at: *high thermal and pluviometric contrasts at all temporal scales*; *high consecutive intervals with extreme temperatures; heat, aridity and long droughts phenomena; excedentary values of precipitation produced in a short period of time, due to a noticeable quantitative reduction of annual average pluviometric potential; increasing of the extreme weather phenomena frequency etc.*

These events lead to discontinuities in the periodic variability of climatic parameters on more or less extensive surfaces, having a negative impact on the environment and in all economic sectors, especially agriculture (the most dependent from weather evolution), inducing reduced opportunities for adaptation. In this context, heat waves is one of the most representative indicators of the general heating process being considered among the top 10 indices /relevant indicators of extreme climate events (Frich et al., 2003), based on daily data of observations.

Genetically defined based on consecutively criterion of the daily maximum thermal deviations from the normal reference period, heat waves are perhaps the most semnificative image of heating producing which affected especially the extra-Carphatian regions of plains and low hills from southern and eastern of Romanian Carpathians.

This paper identifies the annual and seasonal frequency production of heat waves (number of cases) in a multiannual regime, highlighting the intensity of events (number of days affected) and the maximum duration (in days) of episodes with phenomenon, aiming at the same time the spatial distribution of areas prone to their production in the geographical area of the Romanian Plain region.

Defining and genetic framing of the heat waves

Genetically, manifestation of these climatic events throughout the year, both in the extra-Carpathian regions and in the mountain area are related of advections of warm air masses of tropical origin, against a circulation from the southern sector and complementary to it in altitude, coupled with the presence of a field anticyclone at ground level. Given their importance in the context of current trends warming of climate, the heat waves support a wide range of definitions, both nationally and especially internationally, among which:

- *according to the World Meteorological Organisation (Commission of Climatology)*, heat waves are highlighted by a strong heating of the air (>5° deviation from normal day/period), with a persistence of ***at least 6 consecutive days***, due to an invasion of hot air masses over a vast territory or region (Peterson et. al., 2001);
- *according to the National Meteorological Administration*, any significant heating of the weather reveal the presence of an episode of heating; as in the case of cold waves (OMM, CLIVAR, ECA&D şi STARDEX);

▪ *Diaz et al. (2006),* defined heat wave by the number of days when daily maximum temperatures recorded at considered weather stations exceeded the ***95th percentile*** coresponding for each weather stations in part;

▪ *Beniston et al. (2007),* included the heat waves in the list of thermal extremes, highlighted by the succession of at least 6 days in which the maximum air temperatures exceed their corresponding ***90th percentile***, calculated for the period 1961-1990;

▪ STARDEX, CLIVAR, ECA&D, define ***the heat waves as intervals of at least 6 consecutive days with daily maximum temperatures when thermal deviations from multi-annual average of each day (1961-1990) are at least 5°C.***

Croitoru, Moldovan and Sorocovschi (2005), fall ***heat waves*** in the second place, in the category of climate hazards for Romanian Plain region, with a final average of 2.1 for the grades given to hierarchy criteria after Bryant (1991).

The phenomenon presents a ***high degree of vulnerability*** (with scores between 1.5 and 2.5) (Fig. 1), reflecting a high degree of "natural exposure" of the region, with the potential to cause damage, as follows:

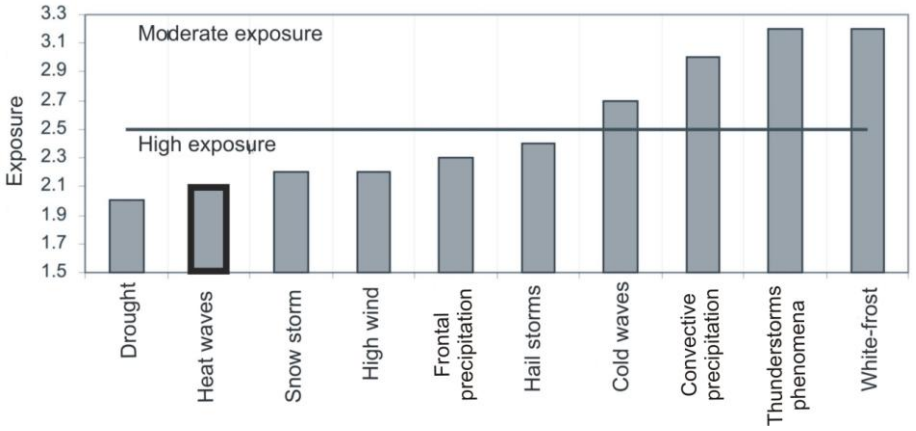

Fig. 1. ***Exposure of the Romanian Plain region to extreme weather events (in the average degrees of evaluation)***

2. DATA AND METHODS

Meteorological data used in this paper, were provided by the National Meteorology Administration (ANM) through the European Climate Assessment and Datasets Project (ECAD, http:\\knmi.eca.nl), covering series of daily maximum air temperature for period 1961-2014, from six weather stations included in the international flow of World Meteorological Organization (WMO), located both in the Romanian Plain region, and its surrounding regions (Danube Valley) (Table 1). Daily series of meteorological data are accessed in this study of type 'non-blended' (from instrumental measurements) and gaps <5%, meeting the requirements of WMO.

Statistical processing was performed on *heat waves defined as intervals of at least three consecutive days throughout the year, corresponding to the percentile 95% values of each daily maximum temperatures in the range mentioned above*.

Table 1. ***Geographical coordinates of the ECAD weather station used for 1961-2014 intervals of the weather data daily sets of the maximum temperatures***

No.	Weather station	Altitude (m)	Latitude	Longitude
1	Bucureşti-Băneasa	90	44º31'	26º05'
2	Buzău	96	45º08'	26º51'
3	Călăraşi	19	44º12'	27º20'
4	Craiova	192	44º19'	23º52'
5	Galaţi	69	45º29'	28º02'
6	Roşiori de Vede	102	44º06'	24º59'

The selected weather stations are representative, have in general clear platforms, which did not change the location and did not interrupt during operation. By default, the series of daily measurements are considered homogeneous and relevant for evidencing the heat waves.

3. RESULTS

Three gradual approaches were followed, dependent on genesis and thermal hazard typology represented by te heat waves in the annual and seasonal multiannual regime: annual and seasonal production frequency (number of cases); duration or persistence of events (number of days); maximum duration (days) of episodes with phenomenon.

The results allowed the identification and support of multi-annual variation of maximum daily temperatures developments generating heat wave in Romanian Plain region.

During the analyzed observations period, the areas most affected by heat waves throughout the year (>120 cases) are those in Oltenia and Vlăsiei Plains, in the surrounding regions of Roşiori de Vede (153), Craiova (137) and Bucureşti-Băneasa (120) weather stations. In the rest of the region, their frequency was pretty close, falling between 108 at Călăraşi and 113-119 in the northwestern and eastern area, at Buzău, respectively Galaţi. With few exceptions, the duration or annual persistence of heat waves sums similarly distributed values between 618 at Roşiori de Vede and 553 days/period at Craiova, respectively 411 at Călăraşi and 454 days / period at Bucureşti-Băneasa (Fig. 2).

Given the restrictive conditions for selection of cases with heat waves (above the percentile 95% corresponding of daily maximum temperatures) annual and seasonal frequency of their occurrence is rather low in value. Warming trend observed in last decades in the southern plains region of Romania, asserts the

unceasing every year frequency of heat waves in this region, which on average ranged from 1-2 cases/year in the first decades of the period analyzed, at over 3 cases/year, after 2000.

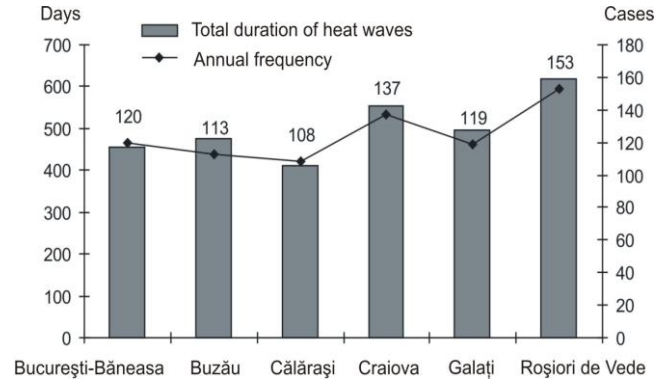

Fig. 2. ***The total duration and the sum of cases of the heat waves (1961-2014)***

The total duration (number of days) of the heat waves (persistence of maximum thermal values) shows a emphasized multi-annual variation, indicating a strong alternation of normal, cold and warm years from a thermal viewpoint, at all six weather stations in this plain (Fig. 3).

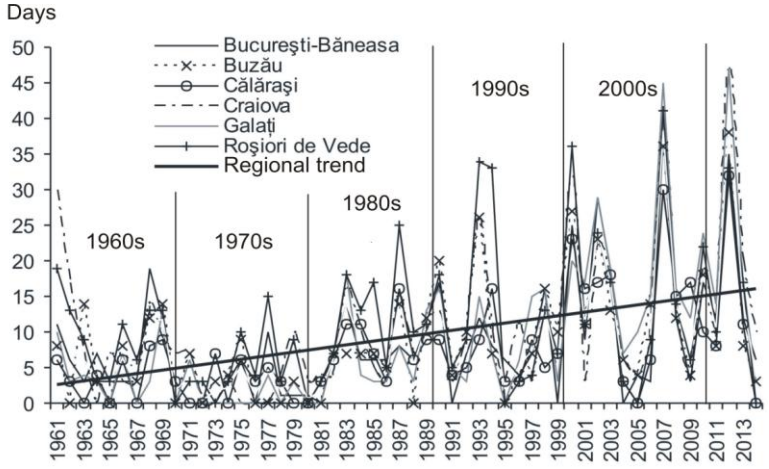

Fig. 3. ***Annual duration (no. of days) of heat waves in the Romanian Plain***

Frequency and duration evolution trend in the period 1961-2014 is upward for the entire region, much higher after 1983 breaking year, indicating the years most strongly affected by heat 2000, 2007 and 2012. Decennial, both the duration and frequency of heat waves occurrence (Fig. 4 a, b) show high value differences, both spatial, and temporal, reflecting significant changes.

In both of cases, one may note the last two decades of the twentieth century and the years after 2010 with the highest frequency of the entire analyzed

period, especially at the weather stations Craiova and Galați for the duration of heat waves gathering most cases, of over 20 days/decade produced during 5, respectivelly 4.5 cases. Decades 1971-1980 and 1961-1970 have the lowest duration, respectivelly frequency, especially at Călăraşi and Galați.

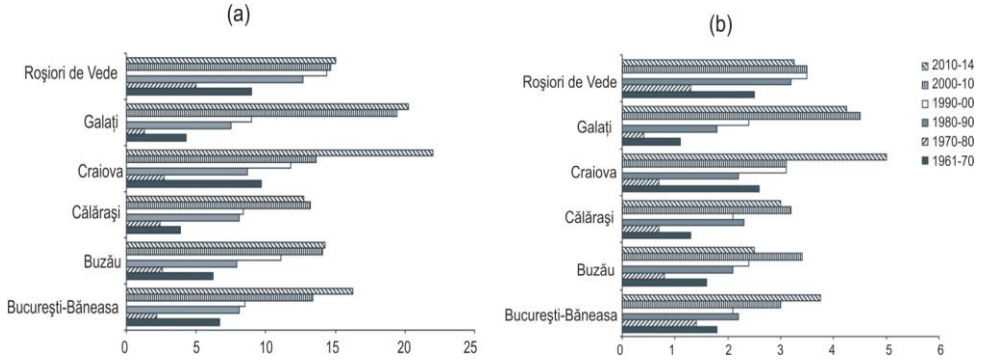

Fig. 4. ***Decennial changes in duration in days (a) and frequency of cases with heat waves (b).***

Seasonal evolution of heat waves highlights important changes over the analyzed period, especially found between the percentage of cases occured during winter, compared to that during the summer (Fig. 5).

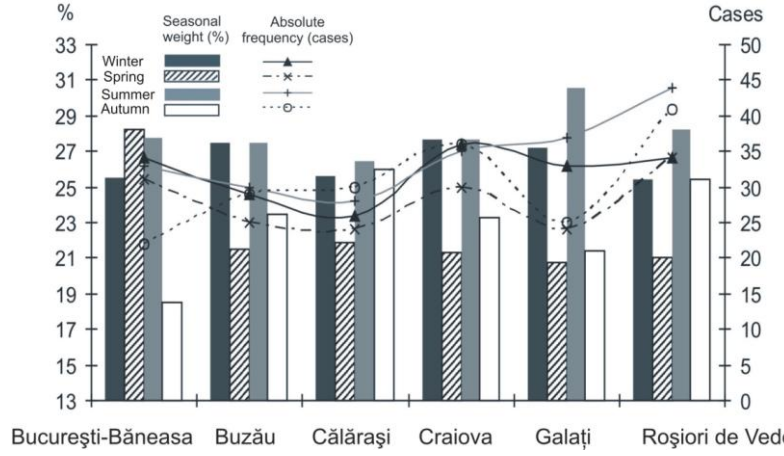

Fig. 5. ***Seasonal weight duration from total duration (%) and number of cases of heat waves (1961-2014).***

Thus at Buzău, Călăraşi and Craiova, the weight of heat waves in these seasons is very close, apart being Bucureşti Băneasa, Galați şi Roşiori de Vede where priority remains the summer ones (Fig. 5). In the transition seasons, although the maximum duration of episodes with maximum warmings have lower weights, autumns are warmer (except Bucureşti-Băneasa weather station).

Also in case of seasonal frequency of cases with heat waves one may note changes in evolution, standing out an almost equal distribution between those

occurred during winter and those occurred during summer at Bucureşti-Băneasa, Buzău and Craiova weather stations. The domination of the excessive heat frequency during summer appears at Galați (33 to 37) and Roşiori de Vede (34 to 44 cases). In the transition seasons, the occurred changes are less obvious, remaining the dominant frequencies with 6-7 cases in autumn as compared with spring at Călăraşi, Roşiori de Vede and Craiova and only 1-4 cases at Buzău, respectivelly Galați. Exception made is Bucureşti Băneasa weather station, where the heat waves in spring are with 9 cases more from those in autumn (Fig. 5).

The maximum duration of selected individual heat waves (Fig. 6) did not exceed 12 consecutive days and occurred during 1993 winter at Buzău and 2007 winter at Roşiori de Vede, and also 2012 summer at Craiova. Those lasting more than 7 consecutive days had a higher frequency after 1980, highlighting also the warmest years in the analyzed period 1989, 1993, 2000, 2007 and 2012 at all analyzed weather stations. The range values frequency class highlights in a multiannual regime, the largest share (68.2%) of those between 3 and 6 consecutive days, while those with durations between 7 to 10 days annual reach 22.7%. The annual share of persistent warming (over 10 consecutive days) is much lower (9.1%).

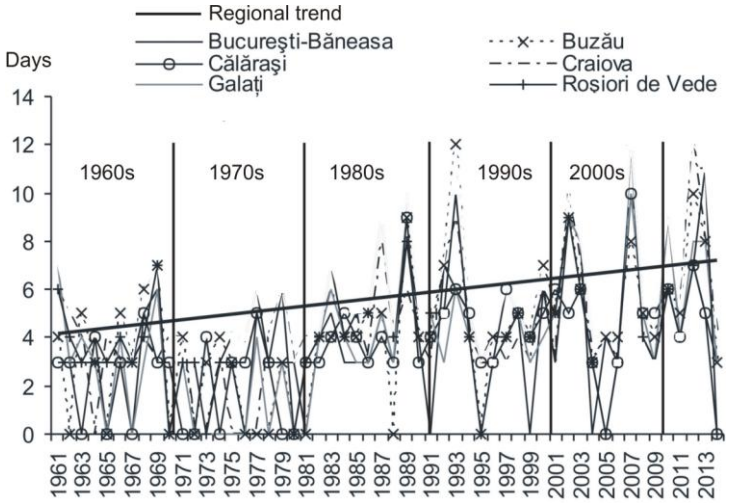

Fig. 6. ***Variation of maximum duration of individual heat waves***

Cumulated decennial annual durations, as well as seasonal durations support the general warming trend in the Romanian Plain region, more visible in the last two decades with about 5-7 days/decade, as evidenced by the estimated regression line, in line with the regional positive trend of the annual duration of heat waves and about 0.2-0.5 days/decade of maximum duration of individual heat waves.

According to Mann-Kendall non-parametric test, most sustained upward trends of the maximum duration of heat wave (no. days) there are specific of the weather stations situated in the southeastern and central part of the Romanian Plain region, indicating a significant trend of increasing, spring at Călăraşi (+0.5

days/period) and summer at Roşiori de Vede (+0.7 days/period), respectivelly Bucureşti-Băneasa (>95% significance level) and autumn, only at Bucureşti-Băneasa (>90% significance level).

4. CONCLUSIONS

The methodology adopted for defining the three parameters of the heat waves generated by situations of excessive heating is suitable for the purpose, considering the heat waves as succession of ≥ 3 consecutive days with maximum temperatures corresponding to 95% percentile, framing maximum temperatures of over 35°C.

The results obtained show visible changes in the positive evolution of the frequency, magnitude and duration of the heat waves at a regional scale, with a concentration of their higher values after 1990 and especially after 2000, framing at Romania level, the southern and south-eastern regional plain among areas with the most pronounced growth rates of the persistence maximum temperatures generating extreme thermal phenomena.

The main factors which explain the recent emphasis of positive thermal extremes with direct response in the frequency and persistence of heat waves are identified through intense thermodynamic processes and deadlocks over Central Europe in summer, and also the domination of southern movement components in winter, which is the most targeted season by warming. Thus, at seasonal scale, one may observe an increase of frequency and duration parameters of heat waves during winter as compared with other seasons. The autumn presents the lowest evolution trend of maximum temperatures.

The maximum thermal intensities of heat waves were reached in 2000 (Craiova 42.3 °C and Bucureşti-Băneasa 42.2 °C) and over more extensive areas in 2007 (Roşiori de Vede 42.7 °C, Craiova 42.6 °C, Galați 40.5 °C, Buzău 40.3 °C).

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