HEAT RISKS IN BULGARIA DURING 2003-2012 PERIOD

V. Ivanov[1], *S. Evtimov*[2]

[1] National Institute Of Geophysics, Geodesy and Geography, ul.Acad.G.Bonchev, bl.3, Sofia 1113, Bulgaria, e-mail: vivanov@geophys.bas.bg

[2] Sofia Univecity "St. Climent Ohridski", Faculty of Physics, Department of Meteorology and Geophysics, 1164 Sofia, Bulgaria, evtimov@phys.uni-sofia.bg

Abstract: A sample of twenty seven weather stations is used to estimate the heat stress risks in Bulgaria during the period 2003-2012. The values of Steadman's heat index at primary or intermediate standard hours are used for this purpose. The range of the index is recoded into five levels of risk and the observations are cross-classified on stations and risk categories. Three frequency tables are produced and analyzed. The table for non-mountain stations and warm period May-October is biploted and stations are clustered according to risks. Geographical distribution of the heat stress risks is established. The heat waves during the period under consideration are discussed.

Key words: biometeorology, Bulgaria, heat index, heat waves, correspondence analysis biplot

Introduction

A living body constantly produces heat. If the heat excess is not shed to the environment, the conditions for physiological heat stress arise. The heat stress is the disturbance of the human thermoregulatory system, which can cause a number of heat-related illnesses: heat fatigue, heat syncope, heat exhaustion and heat stroke (Starr and Mcmilllan, 2008). A high level of the heat stress poses a health risk to anyone engaged in outdoor activity over a short period of time. A significant weather hazard to public health is the so-called heat waves. They are the prolonged episodes of excessive heat stress that occur in synoptic situations with pronounced slow development and movement of the hot air mass. There is ample evidence that the heat waves are associated either directly or indirectly with increases in morbidity and mortality (Robine et al., 2008).

At hot weather, the human body cools off through perspiration because heat loss by radiation and convection ceases and in practice only sweat evaporation takes away the heat from the body. Slowing down the rate of the evaporation, a high humidity retards the loss of the surplus heat. This is why humid days feel hotter than the actual temperature. Steadman (1979) quantifies the combined effect of high temperature and humidity on the human body by the values of the apparent temperature commonly referred to as the heat index (HI). More precisely, the HI is ambient temperature adjusted for variations in vapor pressure above or below some base value (Steadman, 1979). Since 1984 United States National Whether Service of the National Oceanic and Atmospheric Administration (NWS) has routinely employed the HI in order to alert the public and relevant authorities to the hazards of heat waves (NWS, 1994).

The objective of this paper is an evaluation of the heat stress hazard in Bulgaria during the period 2003-2012. The reports of 27 weather stations are used to compute the daily summarizes of extremes of the *HI* for each station. After NWS we categorize the *HI* in levels of risk, cross-classify the observations on the risk categories and the stations and build respective frequency tables. The stations index the rows of the tables and the categories of risk the columns. An entry of the table is the number of observations that share a station and a risk level. We use these tables to reveal the correspondences and structural relationships between different stations and categories of risk. The statistical method of correspondence analysis biplot (Gabriel and Odoroff, 1990; Greenacre, 1993) is applied for this purpose. Providing a joint display of the stations and risk categories as points on the plane, this technique visualizes the major features of the underlying correspondences between the stations and risks.

Section 2 gives general information for *HI* and heat waves. Section 3 presents the data and their preprocessing and preliminary analysis. In Sec. 4 we biplot the frequency table for station and risk categories and reveal the inherent statistical correspondences between stations and risks during warm period May-October as well as the geographical distributions of the heat hazard. The heat waves during the period under consideration are discussed in Sec. 5. Section 6 summarizes the results.

Heat Index and heat waves.

Heat Index is an index that combines the thermal and humidity effects on the body and represents them in one value. The index is developed by R. G. Steadman (1979) who terms it apparent temperature. Steadman uses the achievements of human physiology and clothing science and models the human sensation of the heat by a complex collection of equations. To simplify the computations he fixes a number of parameters to their typical values. Here we quote only some base atmospheric and human parameters. The model accepts an atmospheric vapor pressure of 1600 Pa, a barometric pressure of 1013 hPa, a wind speed of 2.5 m s^{-1} and a zero extra radiation. The base human parameters are as follows: height - 1.7 m, weight - 67 kg, clothing cover - long trousers and short-sleeved shirt or blouse at 84% coverage and activity - a person walking outdoors at a speed of 1.4 m s^{-1} (180 W m^{-2}).

Steadman summarizes his results as a table that gives the *HI* as discrete function on the air temperature and the humidity. For operational purposes Rothfusz (1990), approximates Steadman’s table by 9-term and later NWS (http://i4weather.net/hiwc.html) by 16-term polynomial multiple regression equations. Schoen (2005) offers an exponential fit which more closely approximates the Steadman's table and has only 3 fitting parameters. The corresponding computational formula is:

$$HI = t - 1.0799\, e^{0.03755\, t}\, [1 - e^{0.0801(t_d - 14)}], \qquad (1)$$

where *HI* is the heat index, *t* is ambient dry bulb temperature, t_d is dew point temperature, all in degree Celsius. Note that the values of *HI* are computed for shady and light wind conditions. Exposure to full sunshine can increase *HI* by up to 8.4 °C. A strong hot and dry wind is extremely hazardous since it adds the extra heat to the body. Old people and children are more vulnerable to high *HI*.

The World Meteorological Organization has not yet defined the term heat wave (Koppe et al., 2004). Generally, a heat wave is a period of excessive heat and high humidity relative to location and time of year. In Europe, the definitions of heat wave are operational and they are based on absolute or relative thresholds for air temperature, air temperature and minimum duraton, or indices that are combination of both air temperature and humidity (Koppe et al., 2004). Robinson (2001) adopts that there is a heat wave if the conditions of the NWS for excessive heat alert present for a minimum duration. The NWS issues excessive heat alert when the daytime *HI* reaches 40.6 °C and the nighttime *HI* stays above 26.7 °C for two consecutive days (NWS, 1994)). This base definition is for entire United States but regionally the thresholds and the duration can vary considerably.

Data, preprocessing and preliminary analysis

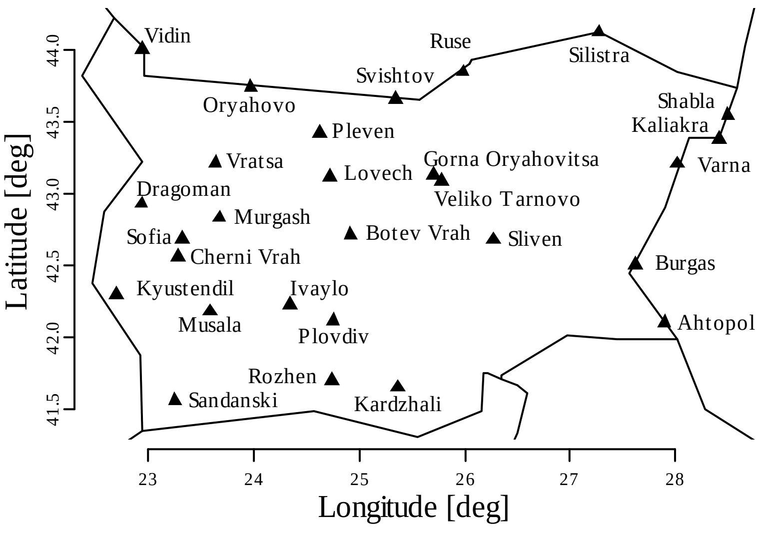
We analyze the heat stress risks at 27 meteorological stations in Bulgaria for the period 2003/01/01-2012/12/31. Figure 1 displays the spatial distribution of the stations. The transliteration of station names is after recommendation of the Council of Science of the Institute at the Bulgarian Academy of Science. The five stations Botev Vrah (2376 m), Cherni Vrah (2290 m), Murgash (1687 m), Musala (2925 m) and Rozhen (1723 m), henceforth called "mountain", are at the peaks. The numbers in the parentheses are the elevations above sea level. In determining a *HI*, the simultaneous air temperature and humidity are required. We extract the station records for air temperature and dew point temperature from respective station reports. These reports are downloaded from database of the National Climatic Data Center of United States of America (http://cdo.ncdc.noaa.gov/CDO/cdo.). The observations are at primary or intermediate standard hours 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 Greenwich Mean Time.

The raw data have undergone automated quality control and erroneous or suspect values are flagged. The original data coverage is at least 96% with exception of station Rozhen where coverage falls to 90%. As a rule the gaps in the records are short and disconnected. We fill in the gaps or replace the incorrect data by the linear interpolations of adjacent correct values in respective records.

We compute the values of *HI* by means of the exponential fit (1). To obtain serially complete records, air temperature alone is used when the air temperature is below

23.9°C, when *HI* is undefined. Next we extract the daily summaries of maximum *HI*, minimum *HI* and respective air and dew point temperatures. The result is the 27 multivariate series of length 3653 days.

The HI is a continuous variable but after NWS we recode it into 5 distinct ranges. Each range corresponds to a level of the physiological risk of heat stress. The categories of heat hazard are: “Caution”, “Extreme caution”, “Danger” and “Extreme danger”. The NWS advises Caution when HI is 26.7-32.2 °C. In this case, the fatigue is



Фиг. 1. Locations of the Bulgarian weather stations under consideration.

possible with prolonged exposure and physical activity. The category *Extreme caution* corresponds to an *HI* of 32.2-40.6 °C. Then sunstroke, muscle cramps, and/or heat exhaustion are possible. NWS issues *Danger* warning when *HI* is 40.6-54.4 °C. The sunstroke and the heat exhaustion are likely and the heat stroke is possible in this case. The category is *Extreme danger* when *HI* climbs to 54.4 °C and over. Then heat strokes and the sunstrokes become imminent. We set up also a fifth category “*No stress*” for *HI* below 26.7 °C.

So, we categorize *HI* in 5 levels of hazard. A second categorical variable is the place of the observations. Its 27 levels are the different weather stations. We crosstabulate on these two variables and build 3 frequency tables of size 27×5. The stations index the rows and the categories of heat risk index the columns. A shell contains the number of observations that share a station and a level of hazard. First two tables are for daily maximum *HI* and daily minimum *HI* and all calendar days in the year. Third table is for daytime maximum *HI* but for warm period May-October only.

A survey of our frequency tables leads to following general conclusions. There is not any day of category *Extreme danger* in the data. The mountain stations Musala, Botev Vrah and Cherni Vrah come totally under category *No stress*. As for two other peak stations, there are only 5 days at Murgash and only 9 days at Rojen when the *HI* reaches the category *Caution*. The total count of stressed nights vary from zero for the most of the stations to 12 for Ahtopol, 14 for Burgas and 37 for Kaliakra, 4.4 nights on average. Finally, in practice there is not heat stress during the cold season November-April. The few stressed days in this period fall all into category *Caution* and their count vary from zero for Varna and Shabla to 6 days for Ruse and 8 days for Gorna Oriahovitsa, 2.3 days on average.

Summing up, the heat hazard is dominant in the daytime during the warm period May-October and at non-mountain stations of our sample. For that reason we focus only on the frequency table for the observations at the non-mountain stations during the warm period May-October.

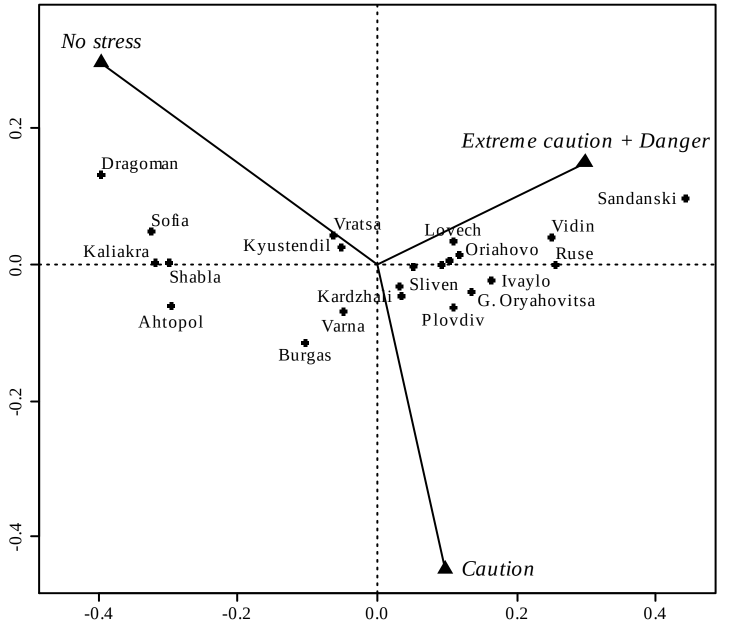
Biplot

So, we have a frequency table of size 22×4. The non-mountain stations index the rows and four categories of heat hazard *No stress*, *Caution*, *Extreme caution* and *Danger* index the columns. Our goal is to reveal the structural dissimilarities and similarities between different station profiles. A station profile is defined as the frequencies in corresponding row of the table divided by its row sum. Instead of working directly by the frequency table we visualize it by the statistical technique of the correspondence analysis biplot. The mathematical basis of this method can be found for example in the article of Greenacre (1993). Here we use a variant of the bipoting of Gabriel and Odoroff (1990). In the case the method optimally displays the stations as points and the categories of hazard as arrows on a two-dimension plot such that the scalar product between a point vector and an arrow approximates the corresponding entry of the matrix of deviations from average profile. The average station profile is defined as the vector of column sums divided by the grand total of the table.

Figure 2 displays the correspondence analysis biplot of the frequency table of the non-mountain stations for period May-October. The points correspond to the stations and the arrows to categories of risk. The points of the stations Pleven, Veliko Tarnovo and Silistra are close to the origin of the plot but they are not labeled in order not to clutter the display. The category *Danger* arises very rarely, from zero for Sofia, Gorna Oriahivitsa and Ahtopol to 8 cases for Sandanski and 10 for Ruse, or 3.1 on average. For that reason we merge *Danger* with the *Extreme caution* in a single category *Extreme caution + Danger*. The biopot representation is perfect because the risk categories are only 3.

As mentioned, the projections of a station point onto a category arrow multiplied by the arrow length, i.e. the scalar product between these two vectors equals to corresponding entry of the matrix of deviation from average profile. The average station profile is 57.3%, 30.0% and 12.7% on the categories *No stress*, *Caution* and *Extreme caution + Danger* respectively. We see that nearly half of the days during the period May-October are stressed by heat. Looking at Fig. 2 we see that projections of the stations in the left half-plane are in direction of the arrow *No stress* and oppose in direction the arrows *Caution* and *Extreme caution + Danger*. Thus these stations have positive deviations from average on category *No stress* and negative deviations on *Caution* and *Extreme caution +*

Danger. Conversely, the projections of the station in the right half-plane are in direction of



Фиг. 2. Correspondence analysis bipot of the non-mountain stations with daytime risk categories during the warm period May-October.

the arrows *Caution* and *Extreme caution + Danger* and oppose in direction the arrow *No stress*. All these stations have negative deviations from average on category *No stress* and positive deviations on *Caution* and *Extreme caution + Danger*. The exceptions of this classification are only Varna with its -0.1%.

Summing up, the biplot clearly splits our sample of stations into two groups. The stations in the left half-plane of the display have positive deviations from average on category *No stress* and negative deviations on *Caution* and *Extreme caution + Danger*. Conversely, the stations in the right half-plane have negative deviations from average on category *No stress* and positive deviations on *Caution* and *Extreme caution + Danger*.

Has our biplot classification some geographical meaning? Figure 3 displays the locations of the stations on the map of Bulgaria together with some of the biplot information. The empty markers represent the stations with higher percentage on category *No stress* and lower percentage on categories *Caution* and *Extreme caution + Danger*. The deviations of these stations from average *No stress* range from 2.9% for Kyustendil to 14.2% for Sofia and 19.6% for Dragoman. We see that lowest hazardous stations are close to west and east borders of Bulgaria. The filled triangles mark stations with higher percentage on categories *Caution* and *Extreme caution + Danger* and lower percentage on category *No stress*. The grey-scale filling of the triangles is according the magnitude of the deviation from the average percentage of category *Extreme caution + Danger*. The darker the filling the larger the deviation. As seen, stations with higher percentages on categories

Caution and *Extreme caution + Danger* and lower percentage on *No stress* are at Danube and in central belt between western and eastern Bulgaria. With exception of Sandanski we

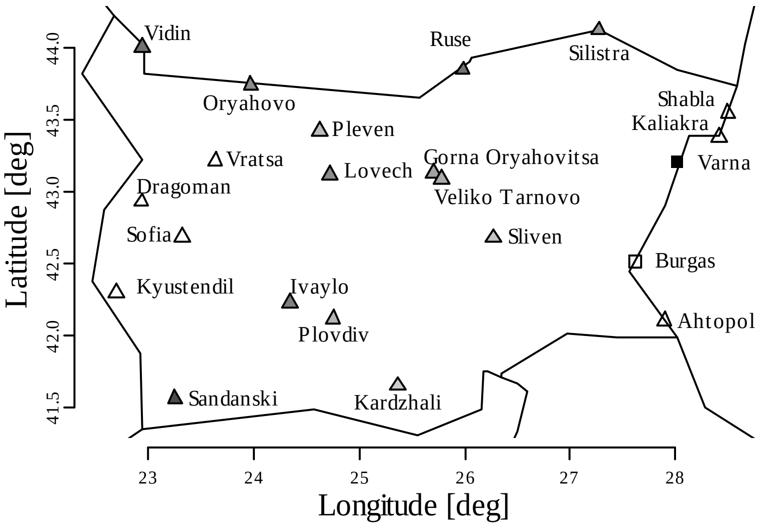


Fig. 3. Geographical partition of Bulgarian non-mountain stations via categories of daytime heat hazard during the warm period May-October.

see also an increasing hazard of category *Extreme caution + Danger* in direction south-north. The deviations from average *Extreme caution + Danger* of these stations vary from 0.3% from Kardzhali to 8.9% and 14.6% for Vidin and Sandanski respectively, 4.3% on average. The stations Varna and Burgas are intentionally marked by squares since they infringe to a certain extent our classification. While the deviations of Varna are -0.1%, on category *No stress*, 2.5% on Caution and -2.5 on *Extreme caution + Danger* the deviations of Burgas on the same categories are 0.6%, 4.1% and -4.8%.

Summarizing, the stations with lower than average heat hazard are close to west and east borders of Bulgaria. The more hazardous stations are at Danube and in central belt between western and eastern Bulgaria. Their hazard of category Extreme caution + Danger generally increases in direction south-north.

Heat waves

In this section we deal with the heat waves in Bulgaria during the period 2003-2012. To define a heat wave we use the criteria based on the excessive heat alert of National Weather Service, Chicago, IL (http://www.crh.noaa.gov/lot/?n=wwadef). Namely, we recognize a heat wave if the maximum *HI* reaches 37.8-40.6 °C and the minimum *HI* stays above 23.9 °C for three consecutive days, or the maximum *HI* reaches 40.6-43.3°C for two consecutive days, or the maximum *HI* climbs to 43.3 °C and over for one day. If there is a heat wave we define its duration as the maximum number of successive days that satisfy some of above mentioned criteria.

Generally the heat waves are comparatively rare events. The heat wave during the period 22-25 Jul 2007 is with broadest coverage and intensity. It is depicted on Figure 4. The bold face numbers give the duration of the heat wave at respective stations. The plain

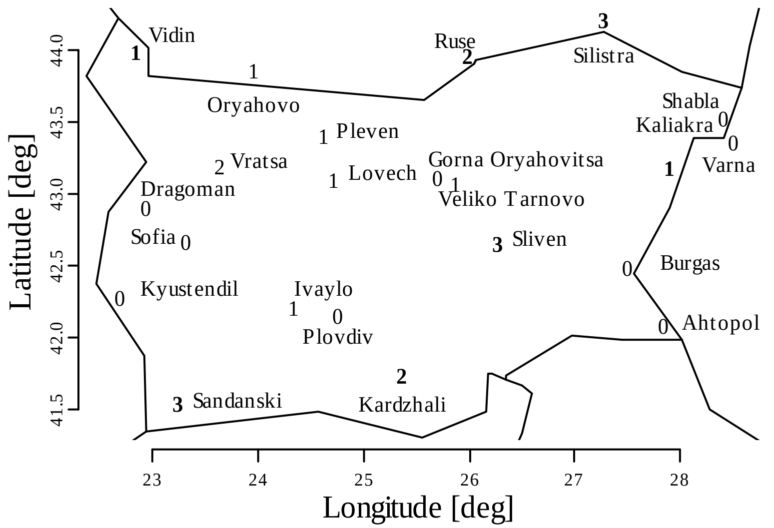


Fig. 4. Coverage and duration of the heat wave 22-25 Jul 2007.

text indicates a lack of heat wave but presence of the days that share some of our formal criteria for a heat wave. As seen, at stations Silistra, Sliven and Sandanski the duration of the wave is 3 days, at stations Ruse and Kardzhali is 2 days and at Vidin and Varna only one day. The conditions are most severe at Sandanski where daytime *HI* reaches 42.2 °C although the humidity is low. At Silistra the maximum daytime *HI* falls to 39.6 °C but the nighttime *HI* stays above 27 °C for three consecutive days. At Ruse and Kardzhali the maximum *HI* vary from 40.8 °C to 42.0 °C and 41.8 °C respectively. At Varna and Vidin the heat waves are only one-day but with highest *HI* of 44.0 °C and 43.3 °C correspondingly. Formally, at Vratsa, Oryahovo, Pleven, Lovech, Veliko Tarnovo and Ivaylo there are not heat waves in view of short duration. At Vratsa the maximum *HI* is 38.6 °C and 39.5 °C and above 24.8 °C and 25.5 °C in the night for 2 consecutive days. The daytime *HI* climbs to 42.9 °C at Oryahovo, 41.0 °C at Pleven, 41.2 °C at Lovech and 40.9 °C at both Veliko Tarnovo and Ivaylo. There are neither days nor nights with accordance of our criteria at Kyustendil, Sofia, Dragoman, Plovdiv and Gorna Oryahovitsa. While in Burgas and Ahtopol we have only one night with *HI* above 23.9 °C, at Shabla the hot nights are 3 and at Kaliakra 4.

The year 2012 is also with heat waves. The wave 23-25 August covers Ruse, Vratsa and Veliko Tarnovo. Its duration at Ruse is 3 days where maximum *HI* reaches 41.3 °C on August 25. At Vratsa we have two consecutive days with maximum *HI* of 40.6 °C.

At Veliko Tarnovo the duration of the wave is only one day but the *HI* climbs to 49.3 °C due to very high humidity. The July of 2012 is also very hot, but in out sample we find only one heat wave. It is during 15-16 July at Kardzhali with maximum *HI* 42.9-41.5 °C.

The mid-August of 2010 is hazardous at the area of Varna. During 11-14 August we have 4 days with maximum *HI* of 38.0-39.3 °C and minimum *HI* of 26.0-27.7 °C. At Kaliakra there is not formal heat wave, but the nights are very hot. During 11-20 August the night-time *HI* is above 25.4 °C on August 19 and 30.9 °C on August 14.

Summarizing, the heat waves in our sample of stations are throughout the second half of our ten-year period and they are mainly in the North and South Bulgaria. Note, that in contrast to the prolonged and intense heat wave in western and southern Europe we do not find any heat waves in our data during Jun-August 2003.

Summary and conclusion

The objective of this paper was an estimation of the heat stress risks at 27 Bulgarian weather stations during 2003-2012 period. The *HI* was used for this purpose. We categorize the *HI* into 5 levels of risk, cross-classify its daily extremes on the stations and the risk categories and build 3 frequency tables.

The analysis of the frequency tables for daily maximum *HI* and daily minimum *HI* shows that there is not any day of category *Extreme danger* in the data, the mountain stations Musala, Botev Vrah and Cherni Vrah come totally under category *No stress* and there are only isolated cases of category *Caution* at stations Murgash and Rojen. The survey of the tables shows also that the stressed nights are only 4.4 on average and in practice there is not some heat stress during the cold season November-April. With a high level of certainty we can conclude that the potential risks of heat stress in Bulgaria are only at the non-mountain stations and only during the days of the warm period May-October.

The frequency table for the non-mountain stations and the warm period May-October shows that average station profile on the risk categories *No stress*, *Caution* and *Extreme caution + Danger* is 57.3%, 30.0% and 12.7% respectively. So, during the warm period nearly half of the days are stressed by heat but the cases of category *Caution* exceed more than two times that of the category *Extreme caution + Danger*. In the context of hazard this means that the chance for a fatigue with prolonged exposure and physical activity is at least two times more that a possible sunstroke, a muscle cramps or a heat exhaustion. As for the days of category *Danger* when sunstrokes and the heat exhaustions become likely and the heat stroke possible, they are very rare, only 3.1 days on average for the whole period under consideration. So, we can conclude that despite of the fact that during the warm period May-October nearly half of the days at non-mountain Bulgaria are on average stressed by heat, the days with higher levels of hazard are very rare events.

The biplot for the warm period May-October clearly splits the non-mountain stations into two groups. While the stations in first group have positive deviations of their profiles from average on category *No stress* and negative deviations on *Caution* and *Extreme caution + Danger*, the stations in the second group have negative deviations on category *No stress* and positive on *Caution* and *Extreme caution + Danger*. This means that the stations in the second group are more hazardous that the stations in the firs one. In geographical context the stations with lower than average heat hazard are close to west and east borders of Bulgaria. The more hazardous stations are at Danube and in central belt between western and eastern Bulgaria. More careful inspection shows that generally the hazard of higher risk category *Extreme caution + Danger* increases in direction south-north

The analysis of the heat waves shows that they are comparatively rare events in Bulgaria. We detect only 4 heat waves that meet the requirements of our definition of a heat wave. The heat wave during the period 22-25 Jul 2007 has the broadest coverage and intensity. The wave 23-25 August 2012 is next as coverage. Two other registered heat waves are during 11-14 August 2010 but only at area of Varna and 15-16 July 2012 at Kardzhali. We do not find any signs of prolonged and intense heat wave in western and southern Europe during Jun-August 2003. Note that the heat waves in our sample of stations are only throughout the second half of the ten-year period under consideration

References

Greenacre, M.J., 1993. Biplots in correspondence analysis, Journal of Applied Statistics, 20, 251-269.

Gabriel, K.R. and Odoroff, C., 1990. Biplots in biomedical research, Statistics in Medicine, 9, 469-485.

Koppe C., Kovats S., Jendritzky, G., Menne B.; Baumüller, J., Bitan, A., Jiménez, J.D., Ebi, K.L., Havenith, G., Santiago, C.L., Michelozzi, P., Nicol, F., Matzarakis, A., McGregor, G., Nogueira, P.J., Sheridan, S. and Wolf, T. 2004. Heat-waves: risk and response, World Health Organization Environmental Change SERIES, No.2, Regional office for Europe.

NWS (National Weather Service), 1994. Excessive heat watch, warning and advisory heat index criteria. Regional Operations Manual. Letter E-5-94, Eastern Region, NWS, Bohemia, NY.

Robine, J.M., Cheung, S.L.K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.P. and Herrmann F.R. 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies, 331, 171-178.

Robinson, P.J., 2001. On the definition of a Heat Wave. Journal of Applied Meteorology, 40, 762–775.

Rothfusz, L.P., 1990. The heat index “equation” (or, more than you ever wanted to know about heat index). NWS Tech. Attachment, SR 90-23, 2.

Shoen, C., 2005. A New Empirical Model of the Temperature-Humidity Index, Journal of Applied Meteorology, 44, 1413-1420.

Starr C. and Mcmilllan, B., 2008. *Human Biology*. 8th ed., Belmont: Brooks/Cole.

Steadman, R.G., 1979. The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. Journal of Applied Meteorology, 18, 861–87

Рисковете от горещините в България през периода 2003-2012

В. Иванов, С. Евтимов

Резюме: За оценка на рисковете от топлинен стрес в България през периода 2003-2012 години, е използван е набор от 27 метеорологични станции. За тази цел, са използвани стойностите на heat index на Steadman в основните и междинните синоптични срокове. Интервалът от стойности на heat index е рекодиран в пет нива на риск, и наблюденията са класифицирани по станции и категории на риска. Три честотни таблици са създадени и анализирани. Направен е биплот на таблицата на непланинските станции по време на топлият период Май-Октомври, и станциите са клъстеризирани според рисковете. Установено е географското разпределение на рисковете от топлинен стрес. Дискутирани са топлинните вълни по време на разглежданият период.