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Measuring scales for daily temperature extremes, precipitation and wind velocity

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ABSTRACT: The extreme values of meteorological elements and weather phenomena (extreme events) have a profound influence on human activity. It has long been accepted as part of a weather forecaster's task to predict their occurrence and severity, but without any accepted scales. Here, measuring scales of daily temperature extremes, precipitation and wind velocity have been defined and described. The scales are: standard frequency distribution for daily temperature extremes, decile method for precipitation and the Beaufort scale for wind velocity. Their units are: standard deviation, decile of frequency and unit of the Beaufort scale, respectively. The step 'normal' and three steps for each threshold scale of positive departure from normal are defined: above normal, well above normal and extraordinarily above normal. Also, three steps for each threshold scale of negative departure from normal are defined: below normal, well below normal and extraordinarily below normal. The scales of standard frequency distribution and the decile method can be applied to other extreme values of meteorological elements and weather phenomena if they follow these types of frequency distributions. Examples drawn from the observations of the Meteorological Observatory in Belgrade for the climate period 1961–1990 are presented.

KEY WORDS meteorological thresholds; extreme event; decile method; Gaussian curve of frequency; destructive wind

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1. Introduction

Extreme values of meteorological elements and weather phenomena are nowadays becoming an extraordinary problem in human life and human activity (Jewson and Caballero, 2003; Meze-Hausken *et al*., 2009; Leblois and Quirion, 2011). Extreme events can have severe consequences, especially during extreme seasons (summer and winter) for different social and economic sectors because they may generate serious health problems to the population or may disturb transportation, construction and tourism activities. Also, agricultural crops and yields are very sensitive to extreme climatic events, especially those related to temperature and precipitation. In the general context of climate change, it is considered that temperature, precipitation and wind will be some of the most affected climatic parameters. The changes implied will be in frequency, intensity and persistence. For this reason, in the last decade many researchers have tried to define extreme events in many different ways (IPCC, 2007; Varfi *et al*., 2009; El Kenawy *et al*., 2011; Radinović and Ćurić, 2011; Smith and Lawson, 2012). Even if inside the meteorological community there are reasons for specific indices, the general opinion is that the more indices are used, the better and more reliable view of the changes in the extremes is presented (Perry and Hollis, 2005).

Meteorology today has progressed from a general art and science to a highly sophisticated body of knowledge and technology that may be applied to a wide range of practical activities. In order to realize the full benefit of these applications to the needs of society it is essential to provide professional meteorologists and non-meteorologists with some basic unification for measuring extremes of the meteorological events. Clearly, the time has arrived to provide a method that will allow professionals to identify meteorological thresholds which will become relevant and valuable. For example, knowledge and forecasts about weather conditions continue to be intensely interesting to people (Thornes and Stephenson, 2001). In line with this, even if the forecast is very accurate the users of weather forecasts have to know what 'normal temperature' or 'extraordinary wind speed' mean, and whether these reports are based on the historical archive for a given location. The term 'normal' is region-dependent and will vary from one region to another. Therefore, it is very important to know the meteorological thresholds of extreme events which are obtained using the same methodology and which can be used in weather reports and weather forecasts.

2. Methodology for defining the thresholds

The thresholds can be calculated in different ways (Smith and Lawson, 2012), but experience has shown that for weather elements whose departures from normal follow the normal distribution it is suitable to use the Gaussian curve of frequency distribution (for example, for temperature and pressure). For such weather elements the normal curve of frequency distribution may be used for classification of thresholds (Gibbs, 1987; Wilks, 1995; Changnon, 1998; Coles, 2001; Chan, 2010). The standard deviation (σ) is used in defining thresholds, as shown in Table 1. For weather elements whose departures from normal do not follow the normal distribution (precipitation amounts), a decile method may be used (Gibbs, 1987; Coles, 2001; Radinović and Ćurić, 2009). For such weather elements the seven thresholds are shown in Table 2. For wind speed thresholds the

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Table 1. Area under normal frequency distribution divided by standard deviation (σ).

Standard deviation	Percent of frequency	Term
$< -3\sigma$	0–0.15	Extraordinarily below normal
-3σ to $< -2\sigma$	0.16–2.30	Well below normal
-2σ to $< -\sigma$	2.31–15.85	Below normal
$-\sigma$ to $< +\sigma$	15.86–84.15	Normal
$+\sigma$ to $< +2\sigma$	84.16–97.70	Above normal
$+2\sigma$ to $< +3\sigma$	97.71–99.85	Well above normal
$\geq +3\sigma$	99.86–100.00	Extraordinarily above normal

Table 2. Frequency distribution presented by decile method (D).

Decile	Percent of frequency	Term
1	0.1–10	Extraordinarily below normal
2	10.1–20	Well below normal
3	20.1–30	Well below normal
4–7	30.1–70	Normal
8	70.1–80	Above normal
9	80.1–90	Well above normal
10	90.1–100	Extraordinarily above normal

Beaufort scale can be used as shown, as in Table 3 (Radinović, 1997; Coles, 2001; WMO, 2006).

3. Thresholds of extreme weather elements for Belgrade

The air temperature is considered as one of the most important climate and weather elements. It is, therefore, important to know the limits within which the air temperature should be considered as normal or how much it departs from normal. That is particularly important in situations when the air temperature becomes an extreme weather phenomenon. It represents a local climate feature and will vary from one region to another.

3.1. Thresholds of minimum daily air temperature

As a measure for cold weather, the negative departure of the minimum daily air temperature from the monthly normal value is representative. Conversely, a positive departure of the maximum daily air temperature from the monthly normal value is also representative (Toros, 2011; Smith and Lawson, 2012).

The thresholds of minimum air temperature are derived from the frequency distribution of the minimum daily temperature in 1 month during the normal climate period 1961–1990 for the Belgrade Meteorological Observatory (44°48′N, 20°28′E, 132 m a. m. s. l.). These are given in Table 4. Effectively, the values of thresholds presented are only valid for Belgrade, but the methodology used is suggested to be accepted generally.

A great part of the human population is suffering from weather changes (Kumkel *et al*., 1999; Maheras *et al*., 2006). This has an influence on the human body, psyche and activity. For that reason, weather forecasts and weather reports are frequently accompanied by medical advice (Schaefer, 1990; WMO, 2006). Therefore, it is necessary to define the thresholds of the inter-diurnal changes of the main meteorological elements. The thresholds of the inter-diurnal minimum temperature decrease *per* month are presented in Table 5.

From Table 5 it can be seen that unexpected uniform values of inter-diurnal minimum temperature change from month to month in a year. The normal inter-diurnal changes of minimum daily temperature through the year occurred in the limits between −2.6 and 3.5 °C. Below normal temperatures appear between −6.0 in April and −2.0 °C in June, while extraordinarily below normal temperatures appear between ≤ −6.5 °C in June and ≤ −13.3 °C in February. The last threshold is under the influence of the sudden temperature drop during the winter surge of cold air (Milosavljević, 1987).

Table 3. Thresholds scale for wind speed (B).

Beaufort scale (B)	Type of wind	Speed (m s^{-1})	Term
0–1	Calm to light air	0.0–1.5	Extraordinarily below normal
2–3	Light breeze to gentle breeze	1.6–5.4	Well below normal
4–5	Moderate breeze to fresh breeze	5.5–10.7	Below normal
6–7	Strong breeze to moderate gale	10.8–17.1	Normal
8–9	Fresh gale to strong gale	17.2–24.4	Above normal
10–11	Storm to violent storm	24.5–32.6	Well above normal
≥ 12	Hurricane wind	≥32.7	Extraordinarily above normal

Table 4. Thresholds of minimum daily air temperature in Belgrade (°C) for the period from 1961 to 1990.

Scale		Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Normal	From	2.3	4.3	7.9	11.6	15.3	17.9	19.1	18.9	16.4	12.6	8.4	4.5
	To	−7.2	−4.4	−0.7	4.2	9.0	11.9	13.6	13.0	9.6	4.6	−0.3	−4.6
Below normal	From	−7.3	−4.5	−0.8	4.1	8.9	11.8	13.5	12.9	9.5	4.5	−0.4	−4.7
	To	−13.3	−10.2	−6.7	0.8	5.2	9.0	10.9	10.2	6.9	0.3	−5.0	−8.2
Well below normal	From	−13.4	−10.3	−6.8	0.7	5.1	8.9	10.8	10.1	6.8	0.2	−5.1	−8.3
	To	−20.9	−15.3	−12.6	−1.8	1.7	4.7	9.4	6.8	0.5	−2.5	−7.9	−15.0
Extraordinarily below normal		≤ −21.0	≤ −15.4	≤ −12.7	≤ −1.9	≤1.6	≤4.6	≤9.3	≤6.7	≤0.4	≤ −2.6	≤ −8.0	≤ −15.1

Table 5. Thresholds of inter-diurnal minimum temperature decrease in Belgrade (°C) for the period from 1961 to 1990.

Scale		Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Normal	From	3.3	3.5	3.0	2.9	2.7	2.4	2.4	3.4	2.4	2.4	2.7	2.7
	To	−2.5	−2.5	−2.2	−2.4	−2.2	−1.9	−2.0	−2.3	−2.4	−2.6	−2.6	−2.4
Below normal	From	−2.6	−2.6	−2.3	−2.5	−2.3	−2.0	−2.1	−2.4	−2.5	−2.7	−2.7	−2.5
	To	−5.5	−5.6	−5.5	−6.0	−5.0	−4.9	−4.5	−4.9	−4.9	−5.7	−5.4	−5.4
Well below normal	From	−5.6	−5.7	−5.6	−6.1	−5.1	−5.0	−4.6	−5.0	−5.0	−5.8	−5.5	−55
	To	−10.5	−13.2	−8.7	−11.9	−11.2	−6.4	−8.9	−8.5	−7.6	−8.7	−11.1	−9.3
Extraordinarily below normal		≤ −10.6	≤ −13.3	≤ −8.8	≤ −12.0	≤ −11.3	≤ −6.5	≤ −9.0	≤ −8.6	≤ −7.7	≤ −8.8	≤ −11.2	≤ −9.4

Table 6. Thresholds of maximum daily temperature in Belgrade (°C) for the period from 1961 to 1990.

Scale		Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Normal	From	−2.0	0.8	5.0	12.1	17.6	20.8	23.1	23.1	19.7	12.5	5.0	−0.1
	To	9.4	12.9	17.6	22.8	27.2	29.9	31.6	31.8	28.7	23.8	17.6	11.2
Above normal	From	9.5	13.0	17.7	22.9	27.3	30.0	31.7	31.9	28.8	23.9	17.7	11.3
	To	14.5	19.4	24.3	27.2	30.5	33.1	35.3	35.3	32.4	27.7	22.8	16.3
Well above normal	From	14.6	19.5	24.4	27.3	30.6	33.2	35.4	35.4	32.5	27.8	22.9	16.4
	To	20.2	23.0	28.8	29.7	34.0	35.6	40.1	38.6	34.4	29.2	28.3	22.5
Extraordinarily above normal		≥20.3	≥23.1	≥28.9	≥29.8	≥34.1	≥35.7	≥40.2	≥38.7	≥34.5	≥29.3	≥28.4	≥22.6

Table 7. Thresholds of inter-diurnal maximum temperature increase in Belgrade (°C) for the period from 1961 to 1990.

Scale		Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Normal	From	−3.6	−2.9	−3.5	−3.7	−3.3	−3.3	−3.4	−3.4	−3.6	−3.4	−3.8	−3.2
	To	3.5	3.5	4.1	4.0	3.4	3.1	3.3	3.0	3.1	2.9	3.7	3.1
Above normal	From	3.6	3.6	4.2	4.1	3.5	3.2	3.4	3.1	3.2	3.0	3.8	3.2
	To	7.7	7.0	7.7	7.3	6.4	6.5	5.3	6.0	5.9	6.9	8.0	7.4
Well above normal	From	7.8	7.1	7.8	7.4	6.5	6.6	5.4	6.1	6.0	7.0	8.1	7.5
	To	12.5	10.0	10.3	10.3	13.5	9.6	13.6	10.0	11.6	10.3	11.7	12.0
Extraordinarily above normal		≥12.6	≥10.1	≥10.4	≥10.4	≥13.6	≥9.7	≥13.7	≥10.1	≥11.7	≥10.4	≥11.8	≥12.1

3.2. Thresholds of maximum daily air temperature

The thresholds of maximum daily air temperature in Belgrade are presented in Table 6. From this table it can be seen that the differences between thresholds are smaller in the summer than in the winter months. The maximum daily temperature is considered to be in normal limits on average in January from −2.0 to 9.4 °C and in July from 23.1 to 31.6 °C. The daily maximum temperature above normal is considered to be from 9.5 to 14.5 °C in January and from 31.7 to 35.3 °C in July. The threshold of extraordinarily above normal of daily maximum air temperature varies between 20.3 °C in January and 40.2 °C in July. These extremes in the summer months are mainly related to heat waves which affect human health, cause damage to the urban infrastructure, or disrupt services due to the excessive consumption of energy for cooling (Kalkstein, 1991; Beniston and Diaz, 2004; Radinović and Ćurić, 2011).

The thresholds of the inter-diurnal maximum temperature changes *per* month in Belgrade are shown in Table 7. From this table it can be seen that the thresholds for normal changes of daily maximum temperature are from −3.8 °C in November to 4.1 °C in March. The thresholds for inter-diurnal maximum temperature changes above normal are between 3.0 °C in October to 8.0 °C in November. The inter-diurnal rise of maximum temperature over 9.7 °C in June and 13.7 °C in July is considered to be extraordinarily above normal.

Table 8. Thresholds of daily precipitation amounts in Belgrade (mm) for the period from 1961 to 1990.

Scale	Deciles	Amounts (mm)
Extraordinarily below normal	1	0.1–1.7
Well below normal	2	1.8–4.2
Below normal	3	4.3–8.0
Normal	4–7	8.1–21.0
Above normal	8	21.1–25.6
Well above normal	9	25.7–33.6
Extraordinarily above normal	10	≥33.7

3.3. Thresholds of extreme daily precipitation amount

On many rainy days the amount of rainfall is relatively small. However, even small amounts of rain may create serious problems in many activities, for example during construction. Light rain may make roofing impossible and surveying difficult, whereas heavy rainfall or large rainfall amounts may bring such

Table 9. Number of days with wind speed between defined thresholds observed in Belgrade for the period from 1961 to 1990.

Scale	Type of wind	Beaufort scale	m s^{-1}	Months											
				I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Extraordinarily below normal	Calm to light air	0–1	0.0–1.5	191	176	173	175	184	179	191	189	176	177	172	173
Well below normal	Light breeze to gentle breeze	2–3	1.6–5.4	198	194	181	188	209	238	242	240	237	229	221	226
Below normal	Moderate breeze to fresh breeze	4–5	5.5–10.7	241	218	254	246	251	231	241	239	235	227	239	215
Normal	Strong breeze to moderate gale	6–7	10.8–17.1	235	184	229	233	254	227	239	242	236	214	202	223
Above normal	Fresh gale to strong gale	8–9	17.2–24.4	71	66	91	53	31	24	13	17	16	77	61	82
Well above normal	Storm to violent storm	10–11	24.5–32.6	4	9	3	5	1	1	3	3	0	6	5	11
Extraordinarily above normal	Hurricane wind	≥ 12	≥ 32.7	0	0	0	0	0	0	0	0	0	0	0	0

operations to an extended halt. Many modern roofing materials must be installed during dry periods (Haggard and Mc Cown, 1985). Therefore, extremely small as well as extremely high amounts of precipitation are of interest for statistics (Gibbs, 1987; Donald and Davis, 1992; Coles, 2001; Radinović and Ćurić, 2009; Xuanyi and Xuefeng, 2010). The thresholds for all daily precipitation amounts can be found at the base of Table 2.

According to the daily amounts of precipitation in Belgrade, and using the decile method of frequency distribution, the thresholds shown in Table 8 were obtained. From Table 8 it can be seen that daily amounts between 8.1 and 21.0 mm are considered normal. Amounts between 21.1 and 25.6 mm *per* day are above normal, amounts 25.7–33.6 are well above normal and daily amounts $\geq$ 33.7 mm are considered to be extraordinarily above normal. The last threshold corresponds to reports of local flooding (Milosavljević, 1987).

3.4. Wind as an extreme weather phenomenon

Insurance companies worldwide have established the standard that wind speed of Beaufort Force 8 ($\geq$ 17.2 m s^{-1}) or greater is considered to be destructive. The same is taken to be the threshold for wind speed as an extreme weather phenomenon (Changnon *et al*., 1997; Smith, 1999; Zielinski, 2002; WMO, 2006; Chan, 2010). Table 9 shows the frequencies of wind speed in Belgrade taking into account Table 3 and data for wind speed. From Table 9 it can be seen that the frequency of extreme wind speed (above normal and well above normal) has a very pronounced annual course. In winter they occur on average four times more frequently than in the summer. Below normal, well below normal and extraordinarily below normal wind speeds are rather uniformly distributed throughout the year. Hurricane force winds (extraordinarily above normal) should be considered as catastrophic winds. These do not appear in Belgrade during the climatological reference period.

4. Conclusions

The basic idea exposed in this paper is to show the measuring scales for principal meteorological elements (extreme temperatures, precipitation and high winds). They represent local climate features but they are comparable with the same climate features in different regions. Effectively the values of thresholds presented in this paper are only valid for Belgrade, but it is suggested that the methodology used be generally accepted.

Meteorological information may be imprecise, incomplete and ambiguous, and will be of no use in disaster management without accurate measurement data. The unification of threshold scales and their units for extreme weather phenomena will contribute to a better understanding and quantification of these types of phenomena in different areas in the world. Also, the use of these scales in practice will improve the application of the weather reports and weather forecasts in the process of designing and implementing procedures for reducing the risk associated with the occurrence of a disaster.

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