STATISTICAL CHARACTERISTICS OF EXTREME PRECIPITATION EVENTS AT THESSALONIKI, BASED UPON OBSERVED AND MODELED VALUES

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Abstract

The objective on this paper is to compare the extreme rainfall characteristics, deduced from the best modelled probability distribution functions and the actual precipitation measurements, obtained at the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki meteorological station.

To meet this objective, the proven best models for the simulation of the annual and seasonal extreme rainfall events at the Thessaloniki meteorological station, that is: Generalized Pareto, Johnson SB, log-Pearson and Fatigue Life (3P) probability distribution models, are appropriately applied to generate the extreme rainfall characteristics for the period 1947-2003.

The measures of central tendency and variability, for regular and ordinal data, are calculated -in an annual and seasonal basis- in order to compare the two different approaches. Hence the deviations between and among the measured and the modelled values of rainfall: means, medians, standard deviations, variance, skewness and kurtosis, are compared to demonstrate any existent difference. The deviations between the projected and actual measures of central tendency values are discussed, with respect to the contribution on climate change.

Keywords: extreme rainfall measurements; extreme probability distributions; rainfall simulation

INTRODUCTION

Predicting and adapting to changes of the statistical characteristics of extreme precipitation events in the context of a changing climate is one of the major challenges of the climate change community. The warming is projected to continue and is likely to be accompanied by changes in extreme weather and climate events [1]. According to Cubasch et al. [2], precipitation extremes could increase by more than the (annual or seasonal) mean and may cause more frequent and severe floods in a future warmed climate. Therefore, changes that will potentially observed in the extreme rainfall characteristics are crucial and of a great research interest, due to its enormous impact on humans, their properties and the environment.

Although bibliography seems to be extensive on the studies concerning the projected changes in extreme precipitation [3 - 11], very few researchers [12, 13] examined extreme rainfall characteristics of a single station. Since the geographical structures of the studied area affect substantially the spatial variability of extreme precipitation events, these studies are deemed to be invaluable tools in the prevention of the flood damages by the construction of certain projects, such as drainage systems and dams.

On the other hand, despite the fact that a lot of scientific work has already been done worldwide on the subjects related to the statistical characteristics of extreme precipitation [14 – 20], very few researchers examined the statistical analyses of extreme rainfall conditions by using hourly precipitation measurements [21 – 25]. This could be attributed to the rarity of these data information. However, according to Kanae et al. [26], the study of extreme rainfall occurring on a smaller scale than daily may reveal a more effective presentation of the observed trends. Moreover, the utilization of hourly records is more beneficial, as the heavy precipitation events occurring mainly in the warm period of the year, are characterized by their short duration. In Greece, the studies using hourly precipitation measurements are limited. Particularly, in Thessaloniki the investigation of the diurnal rainfall pattern is the unique example of using hourly rainfall data and was carried out by Giles and Flocas [27].

The purpose on this study is to compare the extreme rainfall characteristics, deduced from the best modelled probability distribution functions and the actual precipitation measurements, obtained at the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki meteorological station. Deviations between extreme rainfall characteristics produced by two other approaches are also discussed, on annual scale, through the utilization of hourly precipitation records.

In Section 2, a detailed description of both the materials and the methodology used, is provided. The analysis of the results of the deviations between the measures of tendency and variability of extreme rainfall datasets, on annual scale, is provided in Section 3. Moreover, the seasonal outcomes of the comparison of the statistical characteristics of the first approach are discussed in this section. The conclusions are drawn in Section 4.

DATA AND METHODOLOGY

The data used in this study are hourly measurements of precipitation obtained at the Meteorological Station of the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki (AUTH) for the period 1947 - 2003. Regarding the homogeneity and the randomness of the examined time series of precipitation, the Bartlett's test of homogeneity and the Cramer's test, respectively, were applied by Stathis and Mavromatis [28] for a little longer period (1930 – 2003). Results indicated great precipitation homogeneity of the data, as well as absence of randomness.

As far as the definition of extreme precipitation is concerned, the selection of a fixed absolute threshold was preferred to percentiles, based on the fact that absolute threshold is deemed to be the most appropriate and efficient technique, as it contributes significantly to the understanding of the impact of extreme rainfalls on the society locally. To be specific, the suggestion of Douka et al. [29] is adopted. Characteristically, they concluded that the value of 6.5mm/h is defined as the hourly threshold of extreme precipitation in Thessaloniki, during the period 1947-2003 and it corresponds to 93% of the total rainfall data (daily precipitation ≥ 0.1mm). Therefore, the data exceeding the aforementioned hourly threshold were classified in annual and seasonal basis.

In order to assess the changes of the statistical characteristics of extreme precipitation events in the studied area, the following three case studies are examined.

- **1st Case Study:** Two sets of rainfall data are employed. The first one (1st set) is consisted of the actual extreme precipitation measurements of AUTH, while the second one (2nd set) contains estimated rainfall values for the period 1947 - 2003. To generate the latter set of data, the parameters of the, proven by Douka and Karacostas [30], best models for the simulation of the annual and seasonal extreme rainfall events at the Thessaloniki meteorological station, that is: Generalized Pareto, Johnson SB, log-Pearson 3 and Fatigue Life (3P) probability distribution models, are appropriately used. Mean value, median, standard deviation, variance, skewness and kurtosis were then calculated for both sets of data, on annual and seasonal scale. The deviations between and among the measured and the modelled statistical characteristics were compared to demonstrate any existence difference. Last but not least, normalization of the data was performed, in order to be better represented and compared graphically.

2nd Case Study: In this case study, the extreme rainfall measurements obtained at the meteorological station of AUTH were separated in two data sets. The first one (1st set) is made up of the odd actual rainfall measurements (x_1, x_3, …), whereas the second one (2nd set) contains the even actual precipitation records (x_2, x_4, …). The statistical characteristics calculated in the 1st case study, as well as the normalized values of the data were also estimated for both sets. The stability of the time series is examined through the present case study.

3rd Case Study: In this last case study, the set of actual precipitation measurements exceeding the threshold of 6.5 mm/h were divided in two time series as follows: 1947 - 1975 (1st set) and 1976 - 2003 (2nd set). The deviations between the actual (1st set) and "projected" (2nd set) measures of central tendency values are then discussed, with respect to the contribution on climate change.

RESULTS

The annual statistical characteristics of extreme rainfall events for both data set of each case study, as well as, the graphical comparison of their probability functions, are provided in Table 1and Figure 1, respectively.

Table 1. Calculated extreme rainfall characteristics for both 1st and 2nd data set of each case study (C.S.), annually.

	1st C.S.		2nd C.S.		3nd C.S.	
Statistical Characteristics	1st set	2nd set	1st set	2nd set	1st set	2nd set
Mean	11.3	11.3	11.1	11.5	11.7	11.0
Median	9.2	9.5	9.0	9.5	9.3	9.1
Standard Deviation	6.2	6.3	6.6	5.8	6.6	5.7
Variance	38.2	39.1	43.3	33.2	43.0	32.6
Skewness	3.0	3.3	3.6	2.0	2.5	3.7
Kurtosis	13.0	14.5	18.2	4.4	8.2	22.4

Regarding the deviations between and among the measured (1st set) and the modelled (2nd set) statistical characteristics of the first case study, no significant difference is found. Moreover, it is worth-noting that the mean value for both data sets appears to be absolutely the same. This could be attributed to the fact that the second data set is consisted of estimated values, being produced by generating random numbers from the parameters of the best fitted, to the actual rainfall measurements, model. As far as the information contained in their probability functions (Figure 1a) is concerned, it seems to be identical. However, the weakness of the Generalized Pareto distribution to simulate the maximum hourly measurements is evident.

Turning now to the changes of extreme rainfall characteristics between the data sets of the second case study, the odd measurements (1st set) tend to be spread over a wider range from the mean value than the even records (2nd set) of the studied period. This remark seems to be consistent with the probability functions of the aforementioned data sets (Figure 1b), since the "red line" is shown to be interrupted at, approximately, 37 mm/h. The latter conclusion is also verified by the almost platykurtic distribution function, as well as its positive skewness. In particular, the skewness of the distribution of the even measurements is smaller than the corresponding one of the odd values, implying the longer tail on the right side of the probability function of the latter data set.

On the question of the outcomes of the third case study, it is apparent from the Figure 1c that they present converging behavior with the ones of the second case study. Specifically, it has been noticed that the "projected" values of the period 1976 – 2003 tend to be placed closer to the mean value than the actual values of the period 1947 – 1975. The above mentioned are also supported through the changes between the 1st and the 2nd data set of the third case study (Table 1). However, the skewness of 3.7 units of the "projected" probability function testifies its longer tail on the right.

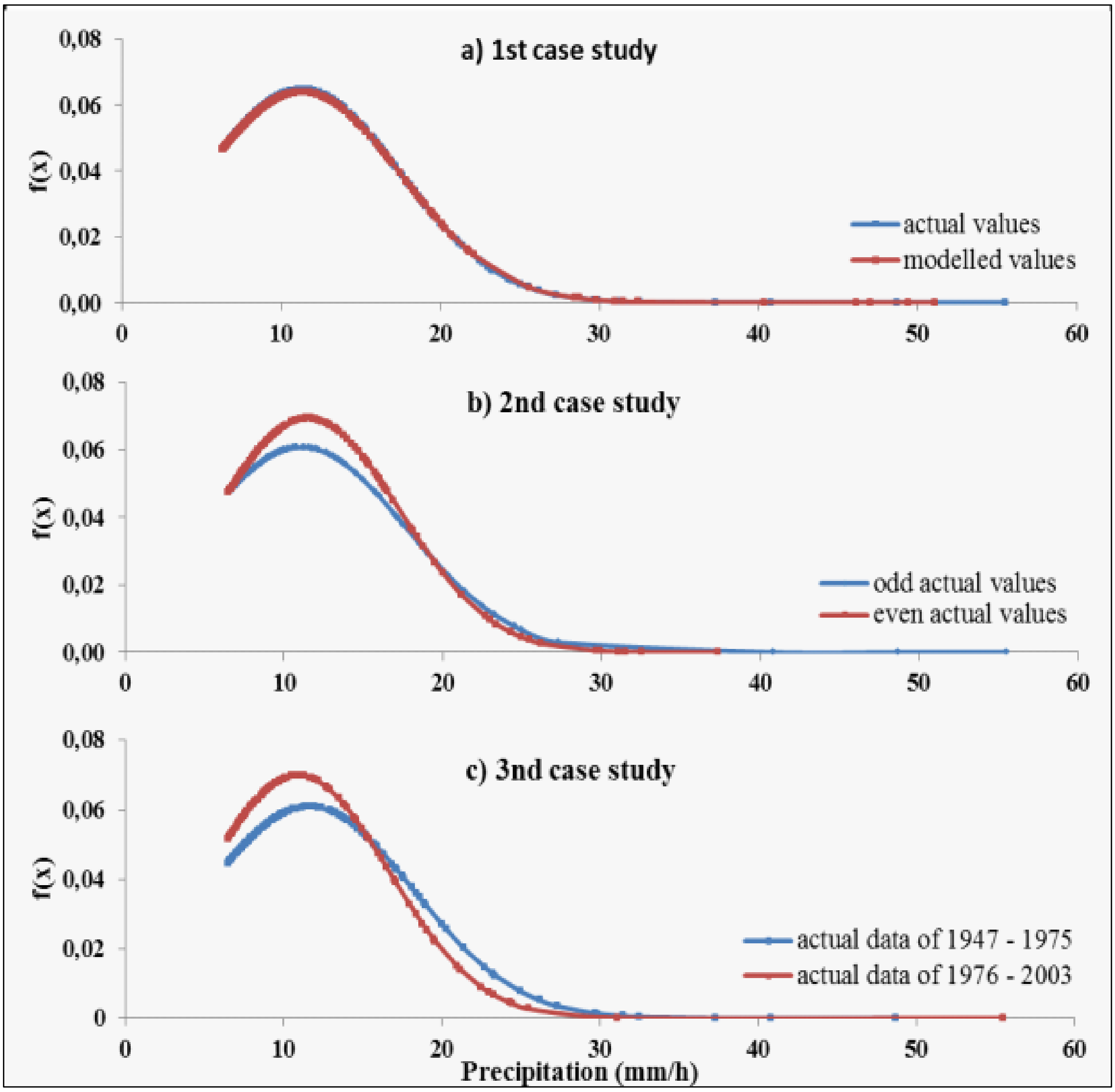

Figure 1. Comparison between (a) actual and modelled values, (b) odd and even actual measurements, and (c) actual data of 1947-1975 and "projected" ones of 1976-2003, on annual scale, for the 1st, 2nd and 3nd case studies, respectively. The x represents the precipitation in mm/h, while the y axis illustrates the frequency.

Concerning the seasonal characteristics of extreme rainfall events for both data set of the first case study, they are presented in Table 2 and in Figure 2, as well. As it can be seen from Figure 2, in winter, no clear difference between the two data sets was observed. In Table 2, the absolute deviations between the actual and modelled measures of tendency and variability are almost identical, as it was expected. As far as the outcomes of the spring and autumn analyses are concerned, no appreciable difference between the characteristics of the two data sets is proved.

On the other hand, in summer, the standard deviation of the actual data is 7.5 units, while the corresponding measure of the modelled data is 5.8 units. In other words, the actual extreme precipitation measurements at Thessaloniki, tend to deviate from the mean value more than the modelled ones. This conclusion is supported by the results in variance, which present a difference of approximately 10 units between the two data sets. Therefore, the distribution of actual data is shown to be more "platykurtic" in summer, relating to the one of the modelled data. Last but not least, it is remarkable that an underestimation of the over 20 mm/h extreme rainfall data has been noticed by the model. This can be attributed to the fact that models often tend to underestimate heavy rainfalls, very cold or very hot temperatures, since their resolution and the numerical differentiations, which ensure their stability in long runs, limit the range of variations of their prognostic variables [31].

Table 2. Calculated extreme rainfall characteristics for both 1st and 2nd data set of the 1st case study (C.S.), seasonally.

	Winter		Spring		Summer		Autumn	
Statistical Characteristics	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mean	9.1	9.3	10.7	11.1	12.9	12.9	10.8	10.6
Median	8.0	8.4	8.9	9.0	10.8	11.5	8.4	8.5
Standard Deviation	2.7	2.8	5.1	5.2	7.5	5.8	5.9	6.2
Variance	7.2	7.7	26.1	26.6	55.7	33.1	34.8	38.3
Skewness	1.5	1.6	2.6	2.1	2.9	2.8	2.4	3.3
Kurtosis	2.1	1.9	8.9	5.2	11.4	13.9	7.3	14.1

CONCLUSION

In the present study, an effort was made to assess the changes of the statistical characteristics of extreme precipitation events in the context of a changing climate. To meet this objective, three case studies were studied. Results indicated that in the first case study, no significant difference between the actual and the modelled measures of central tendency values was present, while in the second case study the stability of both data sets was confirmed. As far as the third case study is concerned, it has been observed that the deviations between the characteristics of actual and "modelled" data behaved in a similar way with the corresponding of the second case study. Last but not least, despite the fact that the estimation of the changes of the extreme rainfall characteristics involves uncertainties, it has been shown that the knowledge of them could act as a useful tool for designing the appropriate infrastructures for prevention of damages.

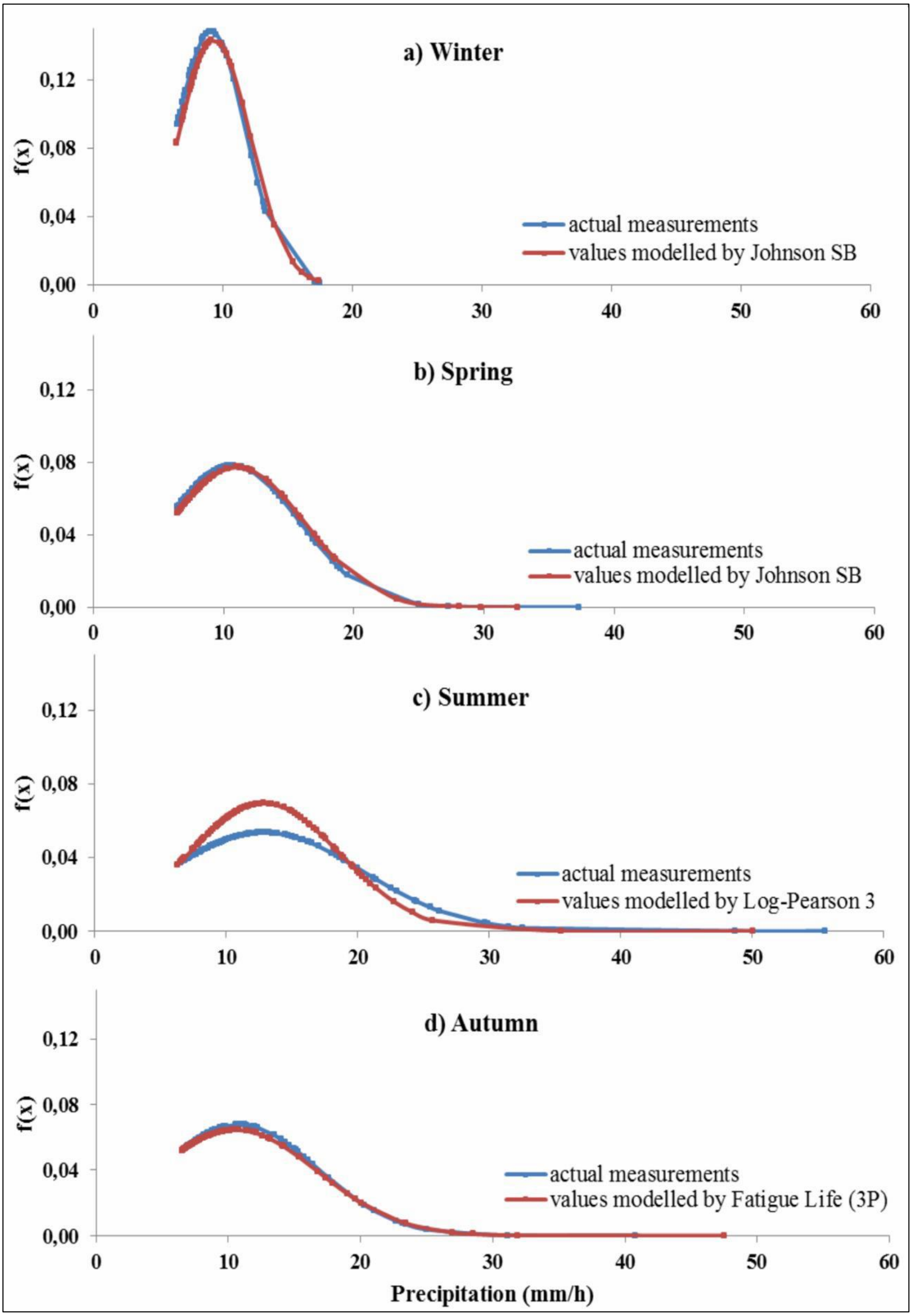

Figure 2. Comparison between actual and modelled values for the 1st case study, seasonally. The x represents the precipitation in mm/h, while the y axis illustrates the frequency.

REFERENCES

[1] J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell & C. A. Johnson. Climate Change 2001: the scientific basis, Cambridge University Press, Cambridge and New York, pp 419, 2001.

[2] U. Cubasch, G. A. Meehl, G. J. Boer, R. J. Stouffer, M. Dix, A. Noda, C. A. Senior, S. Raper & K. S. Yap. Projections of future climate change. Climate Change 2001: The Scientific Basis, J. T. Houghton et al., Eds., Cambridge University Press, Cambridge and New York, pp 525-582, 2001.

[3] X. Gao, J. S. Pal & F. Giorgi. Projected changes in mean and extreme precipitation over the Mediterranean region from high resolution double nested RCM simulations, Geophysical Research Letters, vol. 33, L03706, doi: 10.1029/2005GL024954, 2006.

[4] M. E. Shongwe, G. J. van Oldenborgh, B. van den Hurk, B. de Boer, C. A.S. Coelho & M. van Aalst. Projected changes in mean and extreme precipitation in Africa under global warming, Part I: Southern Africa, Journal of Climate, Netherlands, vol. 22, pp 3819–3837, 2009.

[5] M. E. Shongwe, G. J. van Oldenborgh, B. van den Hurk & M. van Aalst. Projected changes in mean and extreme precipitation in Africa under global warming, Part II: East Africa, Journal of Climate, Netherlands, vol. 24, pp 3718–3733, doi:10.1175/2010JCLI2883.1, 2011.

[6] J. F. Wang & X. B. Zhang. Downscaling and projection of winter extreme daily precipitation over North America, Journal of Climate, Canada, vol. 21, pp 923–937, 2008.

[7] H. Madsen, D. Lawrence, M. Lang, M. Martinkova & T. R. Kjeldsen. Review of trend analysis and climate change projections of extreme precipitation and floods in Europe, Journal of Hydrology, vol. 519, pp 3634–3650, http://dx.doi.org/10.1016/ j.jhydrol.2014.11.003, 2014.

[8] J. Rajczak, P. Pall & C. Schär. Projections of extreme precipitation events in regional climate simulations for Europe and the Alpine Region, Journal of Geophysical Research: atmospheres, vol. 118, pp 3610–3626, doi:10.1002/jgrd.50297, 2013.

[9] I. Kioutsioukis, D. Melas & C. Zerefos. Statistical assessment of changes in climate extremes over Greece (1955–2002), International Journal of Climatology, vol. 30, pp 1723–1737, doi: 10.1002/joc.2030, 2010.

[10] K. Tolika, C. Anagnostopoulou, P. Maheras & M. Vafiadis. Simulation of future changes in extreme rainfall and temperature conditions over the Greek area: A comparison of two statistical downscaling approaches, Global and Planetary Change, Greece, vol. 63, pp132–151, 2008.

[11] B. Mladjic, L. Sushama, M. N. Khaliq, R. Laprise, D. Caya & R. Roy. Canadian RCM projected changes to extreme precipitation characteristics over Canada. Journal of Climate, vol. 24, pp 2565–2584, 2011.

[12] P.S. Chu, X. Zhao, Y. Ruan & M. Grubbs. Extreme rainfall events in the Hawaiian islands, Journal of Applied Meteorology and Climatology, American Meteorology Society, vol.48, pp 502–516, 2009.

[13] H. Hirose. Parameter estimation in the extreme value distributions using the continuation method, Trans. Inf. Proces. Soc., Japan, vol. 35, pp 1674–1681, 1994.

[14] L. Bocheva, T. Marinova, P. Simeonov & I. Gospodinov. Variability and trends of extreme precipitation events over Bulgaria (1961–2005), Atmos. Res., vol. 93, pp 490– 497, 2009.

[15] M. Müller, M. Kašpar, D. Řezáčová & Z. Sokol. Extremeness of meteorological variables as an indicator of extreme precipitation events, Atmos. Res., vol. 92, pp 308– 317, doi.org/10.1016/j.atmosres.2009.01.010, 2009.

[16] X. Xu, Y. Du, J. Tang & Y. Wang. Variations of temperature and precipitation extremes in recent two decades over China, Atmos. Res, vol. 101, pp 143–154, 2011.

[17] S. Fernández-Montes, S. Seubert, F.S. Rodrigo, D.F. Rasilla Álvarez, E. Hertig, P. Esteban & A. Philipp. Circulation types and extreme precipitation days in the Iberian peninsula in the transition seasons: spatial links and temporal changes, Atmos. Res, vol. 138, pp 41–58, 2014.

[18] M. Santos & M. Fragoso. Precipitation variability in Northern Portugal: data homogeneity assessment and trends in extreme precipitation indices, Atmos. Res., vol. 131, pp 34–45, 2013.

[19] X. Song, S. Song, W. Sun, X. Mu, S. Wang, J. Li & Y. Li. Recent changes in extreme precipitation and drought over the Songhua River Basin, China, during 1960– 2013, Atmos. Res, vol. 157, pp 137–152, 2015.

[20] M. Gao, D. Mo & X. Wu. Nonstationary modeling of extreme precipitation in China, Atmos. Res., vol. 182, pp 1–9, http://dx.doi.org/10.1016/j.atmosres.2016. 07.014, 2016.

[21] J.A Winkler. Regional patterns of the diurnal properties of heavy hourly precipitation, Prof. Geogr, vol. 44, pp 127–146, 1992.

[22] F. Fujibe, N. Yamazaki, M. Katsurayama & K. Kobayashi. The increasing trend of intense precipitation in Japan based on four-hourly data for a hundred years, SOLA 1, pp 41–44, http://dx.doi.org/10.2151/sola. (2005–012), 2005.

[23] R.S. Sen. A spatial analysis of extreme hourly precipitation patterns in India, Int. J. Climatol., vol. 29, pp 345–355, 2008.

[24] R. Twardosz. 2010. An analysis of diurnal variations of heavy hourly precipitation in Kraków using a classification of circulation types over Poland, Phys. Chem. Earth, vol. 35, pp 456–461.

[25] G. Lenderink, H.Y Mok, T.C. Lee & G.J. Oldenborgh. Scaling and trends of hourly precipitation extremes in two different climate zones—Hong Kong and the Netherlands, Hydrol. Earth Syst. Sci. Journal, vol 15 (9), pp 3033–3041, 2011.

[26] S. Kanae, K. Oki & A. Kashida. Changes in hourly heavy precipitation at Tokyo from 1890 to 1999, J. Meteorol. Soc. Jpn, vol. 82, pp 241–247, 2004.

[27] B.D. Giles & A.A. Flocas. Diurnal rainfall variations in Thessaloniki, Greece. Theor. Appl. Climatol., vol 41, pp 221–225, 1990.

[28] D. Stathis & T. Mavromatis. Characteristics of precipitation in Thessaloniki area, north Greece, Greece, Fresenius Environmental Bulletin, vol. 18, pp1–6, 2009.

[29] M. Douka & T. Karacostas. Statistical analyses of extreme rainfall events in Thessaloniki, Greece, Atmospheric Research, 2017.

[30] M. Douka, T. Karacostas, E. Katragkou & C. Anagnostopoulou. Annual and Seasonal Extreme Precipitation Probability Distributions at Thessaloniki Based Upon Hourly Values, Perspectives on Atmospheric Sciences, pp 521-527, 2017.

[31] M. Déqué. Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. Global Planet Change, vol 57, pp 16–26, 2007.