

**CLM CLIMATE SCENARIO AND ITS IMPACT ON SEASONALITY CHANGES IN
SHORT-TERM RAINFALL INTENSITIES IN MOUNTAINOUS REGIONS OF
SLOVAKIA**

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The study is focusing on detecting changes in short-term rainfall at 4 selected climatological stations in the mountainous area in the northern part of Slovakia. The aim of the paper was to detect trends and seasonal changes in the future horizons using the outputs of the Community Land Model (CLM) scenario, which is a moderately pessimistic scenario that compares well to current processes in the atmosphere. The scenario was used to compare historical (1960–2000) and simulated future 2070–2100 periods. Finally, the results obtained for the stations from the high mountainous areas, were compared with the results from the southern parts of Slovakia. The results provide an overview of the predicted changes in the seasonality and trends of the short-term rainfall intensities in areas with mountainous climate in Slovakia.

KEY WORDS: short-term rainfall, seasonality, trends, CLM scenario, Slovakia

Introduction

Future changes in extreme precipitation may affect society more directly than variations in most other meteorological observable phenomena, but precipitation is difficult to characterize due to fluctuations in almost all temporal and spatial scales. Evidence for climate change and global warming can be seen as rising global air temperatures, ocean warming, glacier shrinkage, shrinking snow, sea level rise, ocean acidification and, last but not least, an increased number of extreme events (NASA, 2019).

In addition, the intensity of extreme precipitation increases significantly faster at a higher temperature than the rate of increasing the water retention capacity in the atmosphere, called Clausius-Clapeyron. The Clausius-Clapeyron relationship describes the rate of change in saturated vapor pressure, at approximately 7% increase to the degree of warming at typical surface temperatures, and thus sets the rate of increase in extreme precipitation (Trenberth et al., 2003). Climate models are largely used to assess past and forecast for the future, but given their unproven reliability at smaller scales (Tebaldi et al., 2006; Koutsoyiannis et al., 2008), we need more knowledge of the local effects of climate change in order to use long-term observation records to identify potential signals of precipitation changes (Vallebona et al., 2015). For the analysis mainly outputs from regional climate models are used, which are then compared with real observations. For example, the regional climate scenario

RCP 8.5 analyzed the territory of northern Italy to northern Germany. Occurrences of intensive short-term daily and hourly rain show higher intensities and frequency (Ban et al., 2015).

Recent research shows that the increase is likely to occur in intensities of short-term rainfalls with durations less than one day, which may lead to more extreme rainfalls and flashfloods. Analysis of the evidence leading to an increase in extreme short-term rainfalls due to anthropogenic climate change, as well as a description of the current physical understanding of the association between extreme short-term rainfall intensity and atmospheric temperature, is needed to allow society to adapt to expected future changes in short-term rainfall intensity (Westra et al., 2014).

The Community Land Model (CLM) (CLM Community 2020) was created as a collaborative project between scientists from the Terrestrial Sciences Section (TSS) and the Climate and Global Dynamics Division (CGD) at the National Center for Atmospheric Research (NCAR) and the Community Earth System Model (CESM), the Land Model, and the Biogeochemistry Working Groups in the USA (Boulder, Colorado). The model formalizes and assesses ecological climatology concepts. Ecological climatology has a multidisciplinary structure. It is used to understand the impacts of changes in vegetation on the climate that are caused by humans and nature. It studies physical, chemical, and biological processes by which terrestrial ecosystems influence and

are influenced by the climate on various spatial and temporal scales. The main theme is that terrestrial ecosystems are important determinants of the climate through their energy, water, chemical elements, and trace gases. The main parts of the CLM model are surface heterogeneity, bio-geophysics, the hydrological cycle, biogeochemistry, ecosystem dynamics, and the human dimension. The CLM addresses several aspects that allow for the study of two-way interactions between human activities in the countryside and the climate, changes in land cover/land use, agricultural practices, and urbanization (NCAR/UCAR, 2016; UCAR, 2019; Böhm et al., 2006).

This study is focused on an assessment of the predicted changes in seasonality and trends in the short-term rainfall intensities. The predicted changes are represented by data from the CLM scenario. The analysis of mountainous region is represented by four selected climatological station namely: Bardejov, Červený Kláštor, Javorina and Tatranská Lomnica. The periods analyzed for the future changes in short-term rainfall intensities are historical 1960–2000 and the simulated future 2070–2100.

Methods

Detection of changes in short-term rainfall characteristics was performed by using several methods. For the analysis of the seasonality changes the Burn's vector method was used. For the detection of trend changes the Mann-Kendall trend test was used.

Burn's Seasonality Analysis

Burn's vector method (Burn 1997) is used for the estimation of the seasonality of the occurrence of extreme seasonal phenomena. The variability of the date when the maximum rainfall occurs is described by this method, so that the direction of the vector corresponds to the expected day of the occurrence during the year, and its length describes the variability around the expected date of the occurrence. The date of occurrence D_i of the extreme event in the angular value θ_i is given by:

$$\theta_i = D_i \frac{2\pi}{365} \quad (1)$$

The abscissa x and ordinate y of Burn's vector are calculated as:

$$x = \frac{1}{n} \sum_{i=1}^n \cos(\theta_i) \quad (2)$$

$$y = \frac{1}{n} \sum_{i=1}^n \sin(\theta_i) \quad (3)$$

The orientation of Burn's vector θ is calculated as:

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \quad (4)$$

The seasonal concentration index r can be calculated as:

$$r = \sqrt{x^2 + y^2} \quad (5)$$

The orientation of the vector can have a value from 0, which corresponds with the 1st of January to 2π , which corresponds with the 31st of December. The seasonal concentration index can have a value between 0 (the occurrences are uniformly distributed throughout the year) and 1 (the occurrence happens every year on the same date). The results are interpreted in Burn's diagrams.

Mann-Kendall Trend Test

The Mann-Kendall (Mann, 1945; Kendall, 1975) Trend Test is used for the determination and assessing of the properties and significance of the trend of a selected quantity over time. The test is based on the correlation between the order of rows and their time order. The significance of a downward or upward trend is dependent on a steadily decreasing or increasing variable over time. The trend does not have to be linear. (Mann, 1945; Kendall 1975) The test for time series $X = \{x_1, x_2, \dots, x_n\}$ is given by:

$$S = \sum_{i < j} a_{ij} \quad (6)$$

where

S – the testing statistic:

$$a_{ij} = \text{sign}(x_j - x_i) = \text{sign}(R_j - R_i) = \begin{cases} 1 & x_i < x_j \\ 0 & x_i = x_j \\ -1 & x_i > x_j \end{cases} \quad (7)$$

where

$R_{j,i}$ – series of observations,

$x_{j,i}$ – time series.

The test depends on the order of the values as the actual value of the elements. The statistical test depends only on the order of the observation and not on their own values. This property is the result of statistics that do not depend on distribution. Variation of test statistics S is given by (Kendall, 1975):

$$\text{Var}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{j=1}^m t_j(t_j-1)(2t_j+5)] \quad (8)$$

where

n – number of observations,

m – number of groups in the corresponding order and

t_j – appropriate observation.

The significance of the trend is determined using the standardized variable u at the required significance level α given by (Kendall, 1975):

$$u = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S-1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \quad (9)$$

Data analysis

The analysis of the future changes in short-term rainfall intensities was performed by the CLM scenario data. The data were provided by Martin Gera from Comenius University in Bratislava, Department of Astronomy, Physics of the Earth, and Meteorology (Lapin et al., 2012). The scenario used contains data of two time periods of a historical period (1960–2000) and for a future period (2070–2100). The analysis was made for the rainfall durations from 60 minutes up to 1440 minutes. The CLM scenario, which was selected relates well to the current processes in the atmosphere, it is a semi-pessimistic scenario with a predicted increase in the global temperature of about 2.9°C by the year 2100. For the analysis four climatological station were selected: Bardejov, Červený Kláštor, Javorina and Tatranská Lomnica. The area is located in the north region of Slovakia and it belongs to a slightly warm climatic area with a mountain climate and low temperature inversions. The locations of the climatological stations are presented in Fig. 1.

Results and discussion

The first step in the study was to identify and analyze future changes in the seasonality in the short-term rainfall. The results were presented using the Burn's diagram (Fig. 2–4). We can see that the rainfall maxima occurred in the month of July for all stations and each analyzed duration. The lowest differences between historical and future period were detected in the 240 and 1440 minutes rainfall durations. In all climatological stations the shift between the past and future period was less than 5 days to later period, except the Červený Kláštor climatological station, where the shift in the 240 duration was more than 20 days to later period. The highest shifts between the past and future periods were detected in the 120 and 180 minutes rainfall durations where the shifts were 10 days to later period. In the comparison of the analyzed stations the Bardejov

climatological station has the lowest shift between past and future periods, where the shift is app. 5 days. The highest shifts in the occurrence of maximal rainfall events is in the Červený Kláštor climatological station where the shifts between the past and the future periods were between 2–3 weeks to late July. The results of the seasonality changes in the occurrence of rainfall maxima events are presented in the Figs 2–4.

The next step was to analyze the changes in trends of the rainfall intensities. For the past period the analysis of the rainfall intensities shows that there is a prevailing decreasing trend in all durations at all climatological station. Significant trends were detected in Bardejov and Červený Kláštor climatological stations in 180 and 1440 minutes rainfall durations at the 90% of significance level. The analysis show that there is an absence of significant trend changes for the future period at the 90% of significance level using Mann-Kendall methodology. For the future period the increasing trends were detected for all climatological stations and in all analyzed durations.

To analyze the differences between southern and northern parts of Slovakia, the results from climatological stations located in the southern part of Slovakia (Földes, 2018) were used. The seasonal extreme events in the southern region Slovakia show the occurrence in the late July or early August. The climatological stations in the southern part of Slovakia show the opposite trend in seasonality shift as at the northern region climatological stations. The shift in the northern region is from earlier period to later. In the southern part the shift is opposite from later time period in the month to the earlier period.

This is the significant difference between the climatological stations on the south and the north. In the properties of trends in the short-term rainfall intensities, there are not significant differences between the two regions, and it is different for each analyzed station. But the main result in all analyzed station is that there is a prevailing increasing trend not significant at 90% significance level in the short-term rainfall intensities.

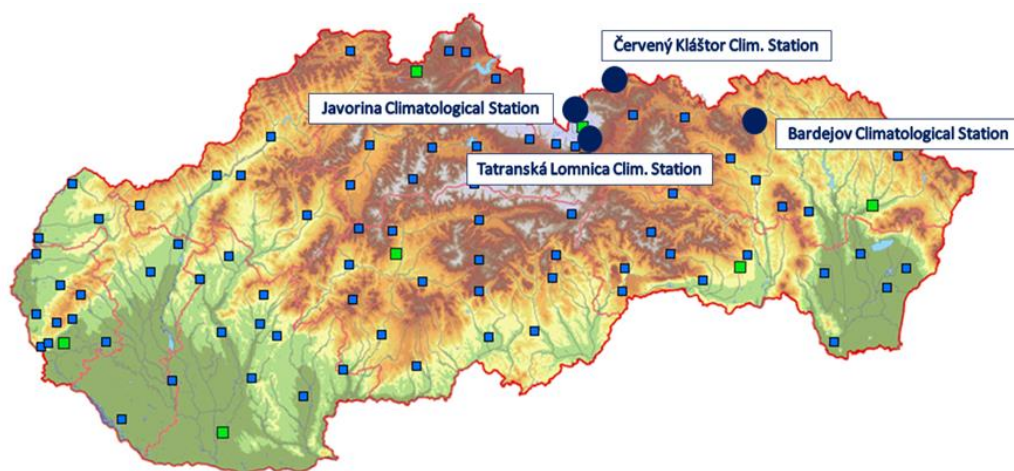


Fig. 1. Locations of the analyzed climatological stations in the Slovak Climatological Network.

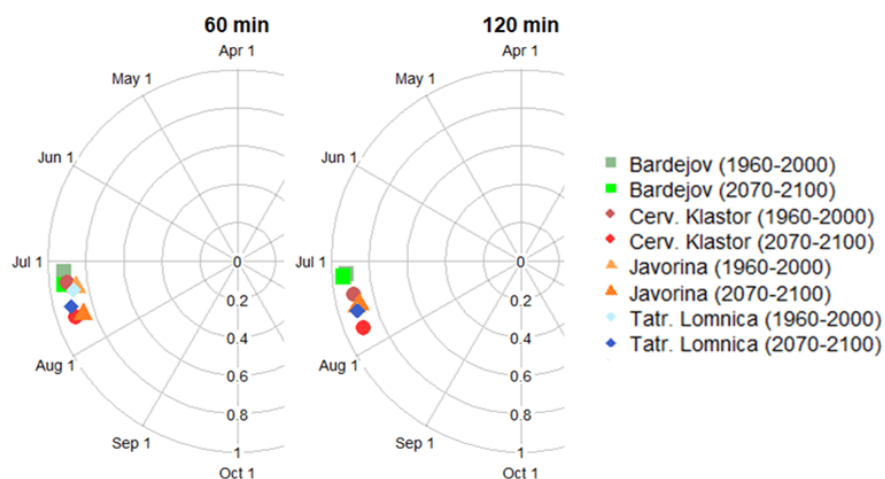


Fig. 2. Seasonality changes for the 60–120 min. rainfall durations.

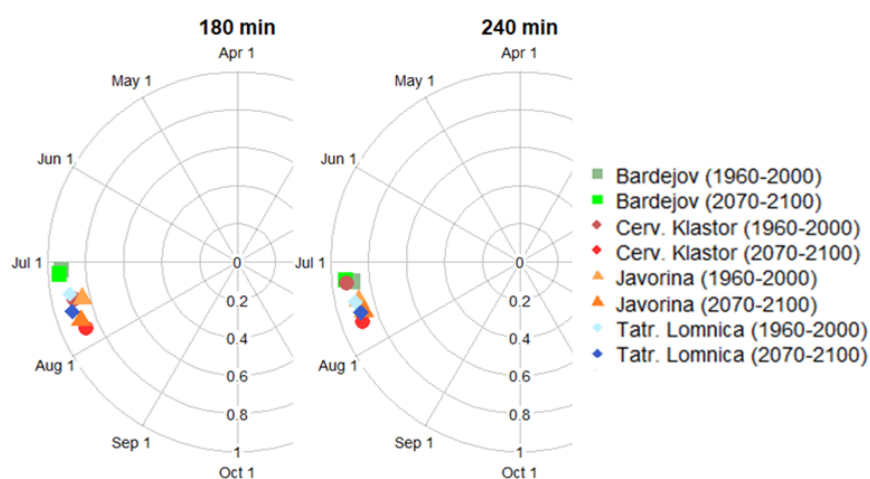


Fig. 3. Burn's diagram for 180–240 min. rainfall duration.

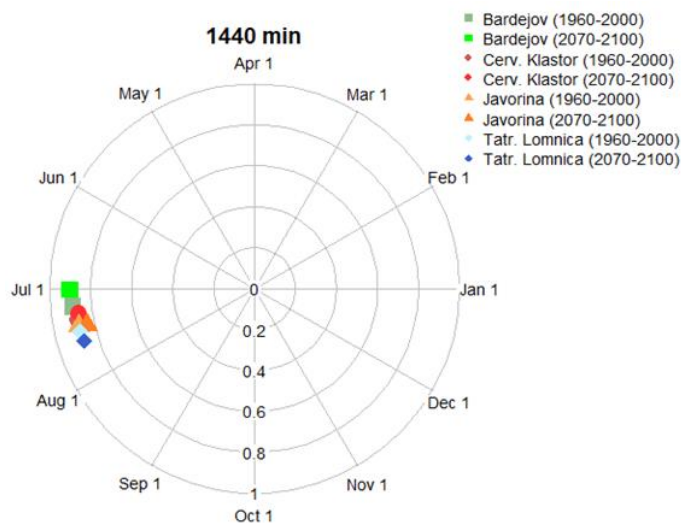


Fig. 4. Burn's diagram for 1440 min. rainfall duration.

Table 1. Trend analysis in the selected climatological stations

Station/Duration	60 min		120 min		180 min		240 min		1440 min	
	hist (1960- 2000)	fut (2070- 2100)	hist (1960- 2000)	fut (2070- 2100)	hist (1960- 2000)	fut (2070- 2100)	hist (1960- 2000)	fut (2070- 2100)	hist (1960- 2000)	fut (2070- 2100)
Bardejov	-	+	-	+	-	+	-	+	-	+
Červený Kláštor	-	+	-	+	-	+	-	+	-	+
Javorina	-	+	-	+	-	+	-	+	-	+
Tatranská Lomnica	-	+	-	+	-	+	-	+	-	+

orange – increasing trend, blue – decreasing trend, dark blue – significant decreasing trend (90% significance level)

Conclusion

This study presents results of the analysis of the predicted changes in seasonality and trends in the short-term rainfall intensities due to climate change represented by CLM scenario. The analyzed mountainous region is represented by four selected climatological station namely: Bardejov, Červený Kláštor, Javorina and Tatranská Lomnica.

The analysis was performed by using Burn's vector method for the seasonality analysis and Mann-Kendall trend test for the detection of trend changes. An analysis was performed for the historical (1960–2000) and future (2070–2100) time periods and for rainfall durations of 60, 120, 180, 240 and 1440 minutes of short-term rainfall. Results show that extreme rainfall events occurred in the month of July. The main findings can be summarized as follows:

- The seasonality of maximal rainfall intensities will be shifted by 5–10 days to later time period in the month of July.
- The lowest shifts are in 240–1440 minutes rainfall durations.
- The highest shifts are in the 120–180 minutes rainfall durations.
- The highest differences between past and future periods are in Červený Kláštor and Javorina climatological stations.
- There is an increasing trend tendency in short-term rainfall intensities. Trend is not significant at a 90% significance level.

These results confirm that short-term rainfall intensities will change in the future and water management measures in the area need to be re-evaluated.

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