# FUTURE CHANGES IN EXTREME TEMPERATURE INDICES IN CLUJ-NAPOCA, ROMANIA

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**ABSTRACT. – Future changes in extreme temperature indices in Cluj-Napoca, Romania.** At present, research in climatology is mainly focusing on climate change and especially on global warming. Since climate change is already affecting large areas worldwide, it is important to study in details these changes at regional and local scale and to reduce its negative impact. The aim of this study is to analyze changes on extreme temperature indices over the periods 2041-2070 and 2071-2100 in Cluj-Napoca city using a set of 21 indices recommended by Expert Team for Climate Change Detection Monitoring and Indices. Extreme temperature indices for observed and modeled data were calculated by employing ClimPACT2 software. Modeled data for daily minimum and maximum temperature was extracted from EURO-CORDEX Project database. RCP4.5 and RCP8.5 scenarios of three regional climate models (RACMO22E, RCA4, and WRF331F) were considered. Next we compared the average values of the historical period (1981-2010) with the 2041-2070 and 2071-2100 periods for each scenario (RCP 4.5 and RCP 8.5) in order to obtain the future changes. The result of this study shows major changes for all the analyzed indices. The period 2071-2100 presents the highest changes under both analyzed scenarios.

**Keywords:** climate change, extreme temperature indices, bias correction, regional climate models, Cluj-Napoca.

## 1. INTRODUCTION

At present, research in climatology is focusing on climate change and especially on global warming. Since climate change is already affecting large areas worldwide, it is important to study in details these changes at regional and local scale in order to reduce its negative impact.

Extreme temperatures are expected to be one of the most affected climatic parameters (Alexander et al., 2006; Kržič et al., 2011; Croitoru and Piticar, 2013). Many studies on historical data indicated significant changes of extreme temperatures (Spinoni et al., 2015; Croitoru and Piticar, 2013). Analysis of climate models projections under different scenarios showed that changes will continue in the future even at higher rates. However, scientific assessments on future climate changes in Romania are very limited (Scripcă et al., 2016; Cheval et al., 2017).

The aim of this study is to analyze changes on extreme temperature indices over the period 2041-2100 in Cluj-Napoca, using a set of 21 indices recommended by Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). These indices have been already used in many previous studies from different regions of the world (Alexander et al., 2006; Kioutsioukis et al., 2010; Kržič et al., 2011; Croitoru and Piticar, 2013).

## 2. DATA AND METHODS

### 2.1. Study Area

Cluj-Napoca is the second most populated city in Romania after Bucharest, the capital, and the largest and most populated urban center in central and northwestern part of Romania. It is located at the contact of Apuseni Mountains and Transylvanian Plateau, in the valley of the Someșul Mic River. The climate of Cluj-Napoca City is temperate continental with weak oceanic influences.

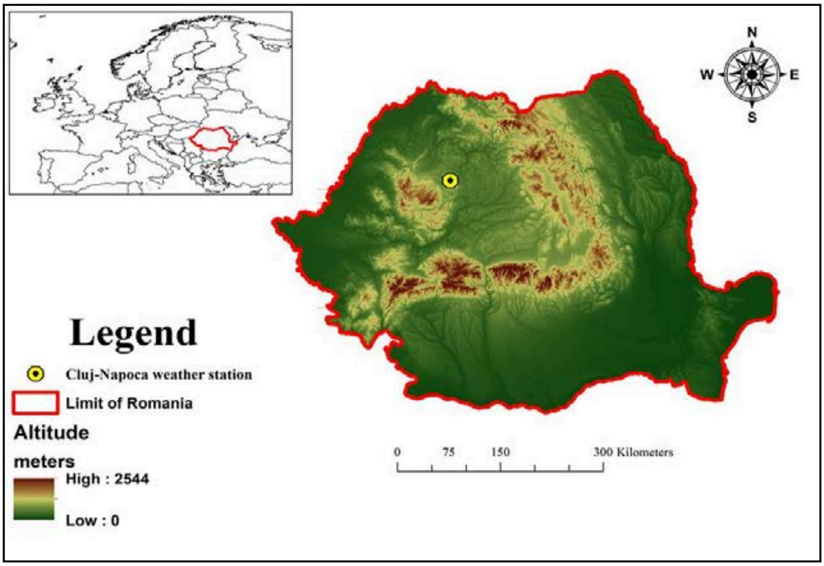


**Fig. 1.** ***Location of Cluj-Napoca weather station***

### 2.2. Data

To identify changes in extreme temperature indices the observed (1981-2010) and modeled (2041-2100) daily maximum and minimum temperature data series of Cluj-Napoca weather station (Fig. 1) has been used. Cluj-Napoca weather station (WMO ID: 15120) is located in northwestern Romania (geographical coordinates 46°46’39” N and 23°34’17” E, 410 m altitude).

The historical datasets, were obtained from the European Climate Assessment and Database project database (non-blend data) (Klein Tank et al., 2002), from www.rp5.ru and by retrieving from synoptic messages available on www.meteomanz.com. The observed datasets were checked for quality control (QC) by the FMETPRO project team (http://fmetpro.granturi.ubbcluj.ro) employing the ClimPACT2 software developed by Alexander and Herold (2016). For modeled data series we analyzed the outputs from EURO-CORDEX project (Jacob et al., 2014), available at https://esgf-data.dkrz.de. The EURO-CORDEX

Project provides an interface of climate simulations to the applicants for climate change impact, adaptation, and mitigation studies. For this study, the simulations were conducted for the spatial resolution 0.1 degree (~12.5 km). Three regional climate models (RCMs) have been selected for this study under RCP 4.5 and RCP 8.5 scenarios: RACMO22E, RCA4, and WRF331F.

### 2.3. Methods

#### 3.2.1. Bias correction

RCM outputs are generally biased and it is necessary to correct them. Therefore, to reduce systematic model errors in the climate variables we used quantile mapping method. It is a method applied to correct biases of regional climate model simulations compared to observational data (Themeßl et al., 2012; Maraun D., 2013). After biases correction we assessed which model overestimate or underestimate temperature values by comparing the observed data with the modeled data in the historical period.

#### 2.3.2. Extreme Indices calculation

A set of 21 extreme temperature indices, recommended by ETCCDMI, were calculated with ClimPACT2 (Alexander and Herold, 2016) for both observed and modeled data. A detailed list and their calculation procedure is presented in Table 1.

**Table 1.** ***List of the ETCCDMI Climate Indices***

| ID | INDEX NAME | DEFINITION | UNITS |
|---|---|---|---|
| Hot Extreme | | | |
| SU25 | Summer days | Annual count when TX (daily maximum) >25°C | Days |
| TR20 | Tropical nights | Annual count when TN (daily minimum) >20 °C | Days |
| SU30 | Tropical days | Annual count when TX (daily maximum) >30 °C | Days |
| SU35 | Very hot days | Annual count when TX (daily maximum) >=35 °C | Days |
| TN90p | Warm nights | Percentage of days when TN > 90th percentile | Days |
| TX90p | Warm days | Percentage of days when TX > 90th percentile | Days |
| TXx | Max Tmax | Annual maximum value of daily maximum temperature | °C |
| TXn | Min Tmax | Annual minimum value of daily maximum temperature | °C |
| TXmean | Mean Tmax | Annual mean value of daily maximum temperature | °C |
| WSDI | Warm spell duration indicator | Annual number of days contributing to events where 6 or more consecutive days experience TX > 90th | Days |
| Cold Extreme | | | |
| FD0 | Frost days | Annual count when TN (daily minimum) < 0 °C | Days |
| ID0 | Ice days | Annual count when TX (daily maximum) < 0 °C | Days |
| FN-10 | Frost nights | Annual count when TN (daily minimum) < −10 °C | Days |
| TN10p | Cool nights | Percentage of days when TN < 10th percentile | Days |
| TX10p | Cool days | Percentage of days when TX < 10th percentile | Days |
| TNx | Max Tmin | Annual maximum value of daily minimum temperature | °C |
| TNn | Min Tmin | Annual minimum value of daily minimum temperature | °C |

| | | | |
|---|---|---|---|
| TNmean | Mean Tmin | Annual mean value of daily minimum temperature | °C |
| CSDI | Cold spell duration indicator | Annual number of days contributing to events where 6 or more consecutive days experience TN < 10th percentile | Days |
| Variability extremes | | | |
| DTR | Diurnal temperature range | Mean difference between daily TX and daily TN | °C |
| GSL | Growing season Length | Annual count between first span of at least 6 days with TG > 5 °C and the first occurrence after 1st July of at least 6 consecutive days with TG < 5 °C | Days |

*TX – daily maximum temperature; TN – daily minimum temperature

### 2.3.3. Changes in extreme indices

To identify future changes, we calculated the indices presented in Table 1 for the historical period 1981-2010 and for the period 2041-2100. The period 2041-2100 was divided into two sub-periods (2041-2070; 2071-2100). Then, we compared the values of the historical period with these two sub-periods for each scenario (RCP 4.5 and RCP 8.5).

## 3. RESULTS AND DISCUSSIONS

### 3.1. Comparison between historical observed and modeled data

To analyze the performance of the bias correction applied by quantile mapping method, we compared observed data with uncorrected modeled data and also observed data with corrected modeled data for 1981-2010 period (Fig. 2).

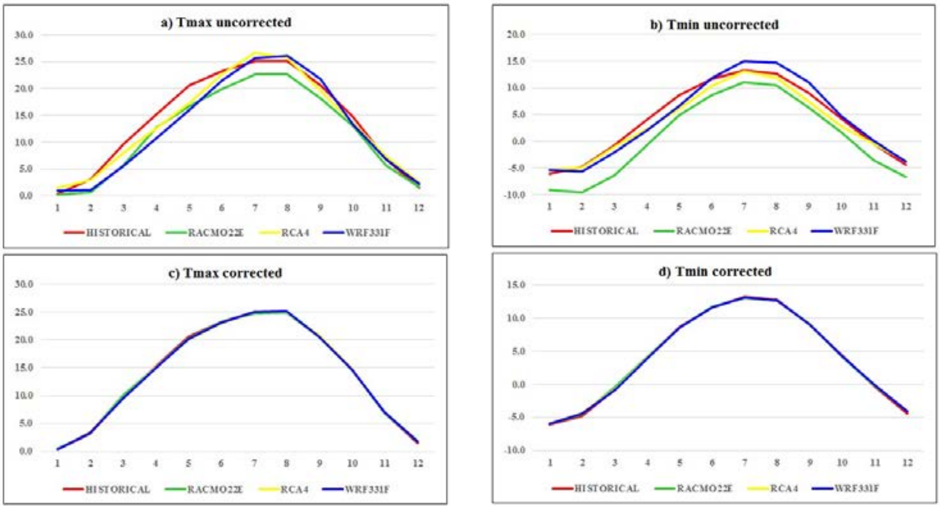


**Fig. 2.** *Average monthly values of observed and modeled data for 1981-2010 period*

Comparison between the historical observed and uncorrected modeled data (Fig. 2a, b) showed that, in general, the three models underestimate both TX and TN. Differences between average values of observed and modeled data were between 0.0 - 4.6 °C for TX and 0.0 - 5.7 °C for TN. After applying the bias correction, historical vs modeled data indicated almost identical values (Fig. 2c,d). The differences between observed and modeled data were found in the range 0.0 - 0.5 °C for TX and 0.0 - 0.4 °C for TN.

### 3.2. Changes under RCP 4.5 scenario

For the RCP 4.5 scenario, the average values of extreme temperature indices over the period 2041-2100 will be higher than the values recorded in the historical period, especially for hot indices, indicating a warming at Cluj-Napoca (Table 2).

**Table 2.** ***Values of extreme indices in the historical period and for the future under RCP 4.5 scenario***

| Indices | 1981-2010 | **RCP 4.5 scenario** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2041-2070 | | | | 2071-2100 | | | |
| | Historical | RACMO22E | RCA4 | WRF331F | Average***** | RACMO22E | RCA4 | WRF331F | Average* |
| SU25 | 60.4 | 66.5 | 79.2 | 86.7 | 77.5 | 72.6 | 87.4 | 86.6 | 82.2 |
| TR20 | 0.2 | 1.9 | 4.1 | 1.8 | 2.6 | 2.9 | 5.7 | 2.9 | 3.8 |
| SU30 | 11.7 | 17.5 | 26.7 | 30.9 | 25.1 | 18.1 | 33.9 | 34.6 | 28.9 |
| SU35 | 0.3 | 1.6 | 2.9 | 4.8 | 3.1 | 1.7 | 4.1 | 4.8 | 3.5 |
| TN90p | 10.4 | 20.4 | 22.6 | 21.6 | 21.6 | 28.3 | 27.1 | 27.2 | 27.5 |
| TX90p | 10.6 | 15.7 | 21.0 | 21.3 | 19.3 | 20.0 | 26.8 | 24.8 | 23.9 |
| TXx | 33.4 | 34.8 | 35.7 | 35.8 | 35.4 | 35.4 | 36.3 | 36.2 | 36.0 |
| TXn | -9.3 | -7.7 | -5.2 | -6.3 | -6.4 | -7.0 | -3.1 | -4.3 | -4.8 |
| TXmean | 14.3 | 15.2 | 16.1 | 16.1 | 15.8 | 16.2 | 16.9 | 16.6 | 16.6 |
| WSDI | 5.0 | 17.7 | 27.9 | 32.7 | 26.1 | 32.0 | 39.9 | 42.5 | 38.1 |
| FD0 | 116.8 | 92.0 | 88.9 | 88.7 | 89.9 | 73.1 | 82.3 | 80.1 | 78.5 |
| ID0 | 35.5 | 28.5 | 17.7 | 19.4 | 21.8 | 16.7 | 9.5 | 12.5 | 12.9 |
| FN-10 | 17.9 | 14.8 | 5.6 | 5.5 | 8.6 | 6.4 | 1.5 | 3.0 | 3.6 |
| TN10p | 10.5 | 4.7 | 2.2 | 3.9 | 3.6 | 2.0 | 1.2 | 2.7 | 2.0 |
| TX10p | 10.6 | 7.7 | 4.3 | 5.7 | 5.9 | 4.7 | 3.2 | 5.0 | 4.3 |
| TNx | 18.7 | 20.1 | 21.3 | 20.5 | 20.6 | 20.7 | 22.1 | 21.1 | 21.3 |
| TNn | -18.3 | -15.8 | -12.3 | -13.0 | -13.7 | -13.7 | -9.1 | -10.6 | -11.1 |
| TNmean | 4.2 | 5.6 | 6.2 | 6.0 | 5.9 | 6.7 | 6.9 | 6.6 | 6.7 |
| CSDI | 3.9 | 4.0 | 1.1 | 1.5 | 2.2 | 1.2 | 0.4 | 1.1 | 0.9 |
| DTR | 10.0 | 9.6 | 9.9 | 10.1 | 9.9 | 9.5 | 10.0 | 10.0 | 9.8 |
| GSL | 234.5 | 256.5 | 261.8 | 260.4 | 259.5 | 271.0 | 273.1 | 268.7 | 270.9 |

*Average of the three models for each sub-period

This increase is more consistent over the period 2071-2100. Most of the cold extreme indices (FD0, ID0, FN-10, TN10p, TX10p) indicate lower values for both future periods and for all models considered. Lower values of these indices also suggest a warming for the future periods.

### 3.3. Changes under RCP 8.5 scenario

As expected, the RCP 8.5 shows that over the period 2041-2100 the values of extreme temperature indices will be even higher compared to those of RCP 4.5 scenario (Table 3). Increasing and decreasing values for different indices for the future periods are consistent with RCP 4.5 scenario.

**Table 3.** ***Values of extreme indices in the historical period and for the future under RCP 8.5 scenario***

| Indices | 1981-2010 | **RCP 8.5 scenario** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2041-2070 | | | | 2071-2100 | | | |
| | Historical | RACMO22E | RCA4 | WRF331F | Average* | RACMO22E | RCA4 | WRF331F | Average* |
| SU25 | 60.4 | 67.5 | 92.1 | 88.6 | 82.7 | 99.8 | 116.4 | 105.7 | 107.3 |
| TR20 | 0.2 | 3.1 | 8.4 | 5.6 | 5.7 | 12.7 | 28.3 | 23.8 | 21.6 |
| SU30 | 11.7 | 17.8 | 36.3 | 39.0 | 31.0 | 34.8 | 59.3 | 57.8 | 50.7 |
| SU35 | 0.3 | 0.9 | 5.4 | 5.9 | 4.1 | 5.2 | 17.2 | 16.0 | 12.8 |
| TN90p | 10.4 | 26.2 | 30.3 | 28.5 | 28.3 | 51.0 | 50.1 | 44.7 | 48.6 |
| TX90p | 10.6 | 17.9 | 28.5 | 24.4 | 23.6 | 33.6 | 41.5 | 38.1 | 37.7 |
| TXx | 33.4 | 34.4 | 37.1 | 36.4 | 36.0 | 37.1 | 39.2 | 39.1 | 38.5 |
| TXn | -9.3 | -7.7 | -4.0 | -5.9 | -5.9 | -4.1 | -1.8 | -3.1 | -3.0 |
| TXmean | 14.3 | 15.7 | 17.1 | 16.4 | 16.4 | 18.1 | 19.0 | 18.3 | 18.5 |
| WSDI | 5.0 | 20.3 | 41.5 | 38.4 | 33.4 | 63.6 | 71.9 | 68.3 | 67.9 |
| FD0 | 116.8 | 75.9 | 76.0 | 81.7 | 77.9 | 44.6 | 51.1 | 55.7 | 50.5 |
| ID0 | 35.5 | 21.5 | 10.6 | 16.0 | 16.0 | 8.6 | 3.9 | 6.6 | 6.4 |
| FN-10 | 17.9 | 9.7 | 3.0 | 5.2 | 6.0 | 3.0 | 0.3 | 0.9 | 1.4 |
| TN10p | 10.5 | 2.8 | 1.1 | 3.1 | 2.3 | 0.6 | 0.2 | 0.6 | 0.4 |
| TX10p | 10.6 | 6.4 | 3.0 | 5.7 | 5.0 | 2.1 | 1.1 | 2.3 | 1.8 |
| TNx | 18.7 | 20.5 | 22.6 | 21.5 | 21.5 | 22.9 | 25.2 | 23.7 | 23.9 |
| TNn | -18.3 | -15.1 | -9.6 | -12.0 | -12.2 | -11.7 | -6.6 | -8.8 | -9.1 |
| TNmean | 4.2 | 6.4 | 7.2 | 6.5 | 6.7 | 8.7 | 9.2 | 8.3 | 8.7 |
| CSDI | 3.9 | 1.9 | 0.2 | 0.7 | 0.9 | 0.0 | 0.0 | 0.3 | 0.1 |
| DTR | 10.0 | 9.3 | 9.9 | 9.9 | 9.7 | 9.4 | 9.8 | 10.0 | 9.7 |
| GSL | 234.5 | 273.4 | 271.5 | 264.1 | 269.7 | 298.3 | 289.2 | 292.0 | 293.2 |

*Average of the three models for each sub-period

The results for the period 2071-2100 shows the most alarming values of extreme temperature indices. Thus, *SU25* shows an increase of 30 days more than the historical average values, representing an increase of 178%; *SU30* recorded an increase of 20 days more than the historical average values (433%); *TXx* recorded an increase of 4 °C degrees more than the historical average values; *TN mean* recorded an increase of almost 4 °C more than the historical average values; *GSL* recorded an increase of 35 days for 2041-2070 period, and 59 for 2071-2100 period more than the historical average values. The results for RCP 8.5 scenario showed that *TNn* and *TNmean* will increase more than *TXx* and *TXmean* indices suggesting that minimum temperature will increase faster than maximum temperature. This is also the case of RCP 4.5 scenario. One of the most spectacular change has been found in a heat wave related index (*WSDI*), which indicates, on average, 5 days for historical observed data, while for the future 33 days for the interval 2041-2070 and 68 days for the sub-period 2071-2100.

## 4. CONCLUSIONS

In this study changes in extreme temperature indices have been analyzed for 2041-2070 and 2071-2100 periods using historical observed data (1981-2010) and modeled data from three RCMs (RACMO22E, RCA4, WRF331F) under RCPs 4.5 and 8.5 scenarios in Cluj-Napoca. After applying bias corrections on RCMs output data, systematic model errors have been significantly reduced. The results show important changes for both future sub-periods compared to the historical one. The period 2071-2100 shows the highest changes in the average values of extreme temperature indices compared to the historical and 2041-2070 periods for both analyzed scenarios. Since present changes in extreme temperature indices will continue in the future at higher rates, this study could be useful as a tool for developing adaptation strategies for Cluj-Napoca.

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