Study of Temperature Evolution’s Trend on the Black Sea Shore, at Constanta

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Abstract. It is widely recognized that temperature’s changes have an important impact on the environment, in particular on sea waters, plants, animals and human life. This article presents the results of the study of the temperature’s evolution trend in Constanta, the main city and harbour on the Romanian Black Sea shore. Have been used the maximum and minimum daily temperatures, collected from the European Climate Assessment & Dataset project website. The data span over 58 years, from 1961 to 2018, period long enough to consider the results significant. Change points detection is done for annual and seasonal data, followed by testing the trend existence for maximum and minimum annual and seasonal series. The results proved the existence of increasing trend for all the temperature series, fact that confirms the global warming effect in this part of the world.

Climate change has an enormous impact on the environment and human life. In time, anthropogenic activity has had such a huge impact on the environment that has generated sometimes irreversible changes in the balance of its natural components [1]. Moreover, due to this activity and natural variability, Earth is getting warmer and warmer. According to NASA’s Goddard Institute for Space Studies (GISS), from 1880 to 2014, our planet’s mean global temperature has increased by about 0.8°C. The 2018 IPCC report [2] emphasized the impact of the global warming of 1.5°C above the pre-industrial levels. This report confirms that the rate of global warming has been steady from 1970 with no indication of any slowdown, beyond the variability induced by known natural factors [3, 4]. Beside the average global temperature, the daily minimum temperature raised more than the daily maximum temperature [5] and is becoming less extreme. As a confirmation, the number of frost days has continuously decreased in Europe [6] to reach almost one day less per year the last 30 years (period 1985-2014), as per last reports of the European Environment Agency [7]. In Switzerland, according to the data offered by the Federal Office of Meteorology and Climatology MeteoSwiss website [8], the number of frost days has fallen significantly, by around 20% over the past 40 years. For data collected during the last decades, many studies of the temperature’s variation trend used parametric and nonparametric regression [9-11] while others emphasize the difficulties of modelling the extremes [12].

In Romania, an analysis of long-term trends reveals the augmentation of the mean temperature in some regions of the country. The increase comes mainly from the augmentation of the seasonal mean temperature during spring and summer [13]. The same happened in North America [14], and Australia [15]. For Dobrogea region, where Constanta belongs to, an analysis made at ten meteorological stations identified an increase by 0.8°C in annual mean temperature after 1997 [16-17]. Lately, in the same
region, at Techirghiol, a study case proved the dependence between the augmentation of the air temperature and that of the water [18].

In this article we focus on the study of the change points in the evolution of the minimum and maximum annual and seasonal temperature. For the detected segments, the trend existence of a monotonic trend is checked and the slope of the trend (if it exists) is provided, using the non-parametric Sen’s method.

1. Data and methodology

1.1. Data

The data used for this article has been collected from the European Climate Assessment & Dataset project website (www.ecad.eu) and contains the daily maximum and minimum temperatures in degrees Celsius from 1961 to 2018 for Constanta city. For Constanta, the data provider is the Regional Meteorological Center Dobrogea, our center being among the 15563 centers and stations worldwide that sends daily reports to this prestigious project. The extreme temperatures are among the 12 characteristic elements of the transmitted observations dataset. As per the project’s policy, no changes have been made to the source data from the participants. In our case, the file contained 21184 entries which 36 out of them were missing. For this analysis, those have been replaced by their interpolated values.

Constanta is situated in south-east of the country, at the latitude of 44.18°N and the longitude of 28.63°E, being the largest harbour on the Romanian Black Sea Shore, with a fervent economic and social life (Figure 1).

Row data has been used to compute the annual mean and seasonal mean (Winter, Spring, Summer and Autumn) series on which the study has been performed.

![Figure 1. Constanta and the Black Sea region (http://www.tour-romania.com/blacksea.html)](http://www.tour-romania.com/blacksea.html)

1.2. Methodology

The methodology used for this study consists in: change points’ detection using the Pettit’s and CUSUM methods, checking the hypothesis of the existence of a monotonic trend, using Mann-Kendall and seasonal Mann-Kendall trend tests and the computation of the slope of the trend (if exists any) using the non-parametric Sen’s method.

1.2.1. Pettitt’s Test

The Pettitt’s test [19] is a non-parametric breakpoint test that determine the most probable change point in a series. To perform it, the studied series is divided into two sub-samples and data in these sub-samples are increasingly sorted. A rank is assigned to the each element and the sum of the ranks of the components of each sub-sample in the total sample is then computed. The test statistic is defined using
the two sums. The hypothesis that there is no change point in the data series is rejected if the p-value computed for the test is less than the level of significance \( \alpha \) (prior chosen).

1.2.2. CUSUM Method

Cumulative sum chart (CUSUM) is a sequential cumulative analysis technique introduced by Page [20] to find the variation of a process usually from mean or standard deviation. CUSUM charts are built by computing and plotting a cumulative sum using a given data series. The charts plot the cumulative sums of the deviations of the sample data from the parameter of interest. These sums fluctuate upwards or downwards showing the trend development. In CPA software [21] used in this study, the parameter of interest is the average and the following relations are used to build the charts.

If \( x_i, i = 1, n \) represent the registered data, the cumulative sums \( S_j \) is:

\[
S_0 = 0, \quad S_j = S_{j-1} + (x_j - \bar{x}), \quad i = 1, n.
\]  

(1)

where \( \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \) is the sample average.

CUSUM charts show the cumulative sum of differences between the values and the average. Because the average is subtracted from each value, the cumulative sum also ends at zero [21].

1.2.3. Mann-Kendall Test

The Mann-Kendall (MK) test is a non-parametric test for trend detection used for independent and randomly ordered data. The null hypothesis \( H_0 \) is that there is no monotonic trend, while the alternative hypothesis, \( H_1 \), which assumes that there is such a trend.

To apply this test, a number is assigned to each element \( x_i (i = 1, \ldots, n) \) of the ordered, then the statistic \( S \) is computed by [22-23]:

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i)
\]

(2)

where

\[
\text{sign}(x_j - x_i) = \begin{cases} 
1 & \text{if } x_j - x_i > 0 \\
0 & \text{if } x_j - x_i = 0 \\
-1 & \text{if } x_j - x_i < 0 
\end{cases}
\]

(3)

If \( n < 10 \) the tables of theoretical distribution of \( S \) designed by Mann and Kendall give the comparison value for \(|S|\) [23].

If the two tailed test is used at a certain level of significance \( \alpha \) and \(|S| \geq S_{\alpha/2}, H_0 \) is rejected. \( S_{\alpha/2} \) is the smallest \( S \) which has the probability less than \( \alpha/2 \) to appear if there is no trend. \( S > 0 \) (\( S < 0 \)) indicates an upward (downward) trend.

If the number of the observed data is greater or equal to 10 (\( n \geq 10 \)), the statistic \( S \) is approximately normally distributed and has the mean zero \( E(S) = 0 \) and the variance \( (\sigma^2) \) given as:

\[
\sigma^2 = \frac{1}{18}[n(n-1)(2n+5)] - \sum t_i(t_i - 1)(2t_i + 5)
\]

(4)

where \( t_i \) denotes the number of ties to extent \( i \) and the terms in the sum exist only the data series contains tied values. The standard test statistic \( z_S \) is calculated as per relation:

\[
z_S = \begin{cases} 
\frac{S-1}{\sigma} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S-1}{\sigma} & \text{if } S < 0 
\end{cases}
\]

(5)
For a chosen the significance level, \( \alpha \) (usually \( \alpha = 5\% \) for which \( z_{0.025} = 1.96 \)), the null hypothesis is rejected if \( |z_S| > z_{\alpha/2} \), consequently that the trend is significant.

The \( z \)-value approach is preferred for small sample sizes \( (n < 10) \), when the calculations can be performed manually. For larger sample sizes, is preferred the \( p \)-value approach and the results are provided by software. With the \( p \)-value approach, the null hypothesis can be rejected if \( p < 0.05 \).

### 1.2.4. Seasonal Mann-Kendall Test

The Seasonal Mann-Kendall test (SMK) is very popular for environmental time series, analysing the monotonic trend in seasonal data. Seasonal can refer to periods as Winter, Spring, Summer, Autumn or other periods as months, days, hours. SMK runs MK test for each of \( k \) seasons, comparing data only to the data from the same season [24]. For each season, the mean and variance are computed adding up the values for all the corresponding periods. These sums are used to find the test statistic as per formula (5).

### 1.2.5. Sen’s slope estimator

This nonparametric procedure developed by Sen [25] is usually combined with MK test. If in MK trend test the null hypothesis can be rejected, the Sen’s slope procedure fits a linear trend to the data, at a certain level of significance.

The Sen’s slope estimator of the real slope is the median of all values of the paired data:

\[
m_i = \frac{x_{j-k} - x_k}{j-k}, \quad i = 1, 2, ..., n, j > k.
\]

This method is robust, insensitive to outliers. Moreover, is more competitive than the linear regression for skewed and heteroskedastic data [26].

### 2. Results and discussion

Mathematical models embedded in the new computer applications extract different behavioural trends of a data set and provide the outcomes in real-time [27]. Is the case of CurveExpertPro that displays a polynomial trend for the annual minimum and maximum series represented in Figures 2. Even if at a visual examination it appears that the annual mean series exhibit a certain trend, a statistical validation is necessary.

![Figure 2](image.png)

Figure 2. (a) Maximum annual and (b) Minimum annual temperatures’ mean series

(retrieved from CurveExpertPro software using the study data)

Before building a specific model for these time series, detecting the change points is necessary since their existence implies different patterns of the series evolution. Table 1 contains the change points detected by Pettit’s and CUSUM methods.

From Table 1 it is obvious that there exist differences between the values for the break points detected by these tests because are based on different techniques. Both tests give a change point in the maximum
and minimum Annual series in the period 1997-1999, no change point in Winter series, a change point in Spring series and different change points for other two seasons.

Table 1. Change points using Pettitt’s and CUSUM methods (retrieved from TimeSeries software using the study data)

| Series | Pettitt | CUSUM |
|--------|---------|-------|
| $T_{\text{max}}$ |         |       |
| Annual | 1997    | 1999, 2003, 2007 |
| Winter | no      | no    |
| Spring | 1988    | 1994  |
| Summer | 1993    | 1986, 1998 |
| Autumn | 1998    | 2000  |
| $T_{\text{min}}$ |         |       |
| Annual | 1997    | 1999  |
| Winter | no      | no    |
| Spring | 1997    | 1998  |
| Summer | 1993    | 1976, 1986, 1999 |
| Autumn | 1998    | 1970, 1997 |

Figures 3 - 6 display graphically the Pettitt’s test results for maximum and minimum Annual, Spring, Summer and Autumn temperatures. Pettitt’s test provides the same change points for the Annual, Summer and Autumn series of maximum and minimum temperatures, while for Winter no change point is found.

Figure 3. Change points for (a) Maximum and (b) Minimum Annual temperatures (Pettitt’s test)

Figure 4. Change points for (a) Maximum and (b) Minimum Spring temperatures (Pettitt’s test)

Figure 5. Change points for (a) Maximum and (b) Minimum Summer temperatures (Pettitt’s test)
Figure 6. Change points for (a) Maximum and (b) Minimum Autumn temperatures (Pettitt’s test)
(The outcomes from Figures 3-6 are retrieved from XLStat software using the study data.)

For both $T_{\text{max}}$ and $T_{\text{min}}$, there is some consistency of the change points values detected by CUSUM procedure and Pettit’s. For Summer series, CUSUM provides 1999 as change point in annual data and 1986 (1998, respectively 1999). This comes in concordance with the scientific findings for other parts of the world, 1999 being flagged as a change point in North America and China [28-29] as well.

Winters seem quite stable, unlike other seasons. Annual series display an increase of about 1.3°C for both $T_{\text{max}}$ and $T_{\text{min}}$, result that confirms the graphical similarities between these series (see Figure 2).

For spring, the increase is between 1.4°C – 1.6°C, but for the summer the jump is higher, approximately 1.8°C – 1.9°C. For autumn, the jump is approximately in the range 0.7°C – 1.2°C. These results confirm that in Constanta, like in other parts of the world, the annual temperature has risen, coming with hotter summers and springs.

Tables 2 and 3 summarize the results of the Mann-Kendall test and the Sen’s slope. For all series but $T_{\text{max}}$ Autumn, the hypothesis of a monotonic trend couldn’t be rejected. The Sen’s procedure detected a significant increasing trend for these series (listed in column 4 of Table 2).

Figures 7 – 10 (diagrams drawn using CurveExpertPro app) graphically display the original data together with the regression lines which slopes have been calculated by Sen’s method.

Table 2. Mann-Kendall trend test and Sen’s slope outcomes (retrieved from TimeSeries software using the study data)

|       | Series                  | p-value | Sen’slope | Comments        |
|-------|-------------------------|---------|-----------|-----------------|
| $T_{\text{max}}$ | Annual                  | 0.000   | 0.036     | Increasing trend |
|       | Winter                  | 0.000   | 0.031     | Increasing trend |
|       | Spring                  | 0.000   | 0.049     | Increasing trend |
|       | Summer                  | 0.000   | 0.054     | Increasing trend |
|       | Autumn                  | 0.163   | 0.013     | No trend        |
|       | Seasonal (monthly)      | 0.000   | 0.038     | Increasing trend |
|       | Seasonal (four seasons) | 0.000   | 0.035     | Increasing trend |
| $T_{\text{min}}$ | Annual                  | 0.000   | 0.035     | Increasing trend |
|       | Winter                  | 0.033   | 0.026     | Increasing trend |
|       | Spring                  | 0.000   | 0.037     | Increasing trend |
|       | Summer                  | 0.000   | 0.051     | Increasing trend |
|       | Autumn                  | 0.000   | 0.051     | Increasing trend |
|       | Seasonal (monthly)      | 0.000   | 0.035     | Increasing trend |
|       | Seasonal (four seasons) | 0.000   | 0.037     | Increasing trend |
Figure 7. Trends for Annual series

Figure 8. Trends for Spring series

Figure 9. Trends for Summer series
Figure 10. Trends for Autumn series
(The outcomes from Figures 7-10 are retrieved from CurveExpertPro software using the study data.)

All charts reaffirm that the raising trends of the temperatures’ series, especially in the last 20 years. The higher slope corresponds to $T_{\text{max}}$ and $T_{\text{min}}$ for Summer and $T_{\text{min}}$ for Autumn. The slopes computed for the seasonal series are not significantly different.

For the subseries obtained by the change points timeline divisions, the existence of an increasing/decreasing trend has been tested and the slopes have been computed by Sen’s method. The results are presented in Table 3, for different significance levels (column 4). Was detected only one significant decreasing trend, for the Summer $T_{\text{min}}$ subseries 1961-1976, while the highest significant increasing trends were found for $T_{\text{min}}$ Autumn subseries 1997-2018 (at 3% significance level) and summer subseries $T_{\text{min}}$ 1999-2018 (at 6% significance level). We notice significant raise of the subseries’ trend after 1995.

Table 3. Significant trends of seasonal time subseries (retrieved from TimeSeries software using the study data)

| Season | period     | Significance level | Sen’s slope | Comments          |
|--------|------------|--------------------|-------------|-------------------|
| $T_{\text{max}}$ | Spring     | 1995-2018          | 7%          | 0.059             | Increasing trend |
|        | Summer     | 1999 - 2018       | 5%          | 0.042             | Increasing trend |
|        | Autumn     | 2001-2018         | 5%          | 0.061             | Increasing trend |
| $T_{\text{min}}$ | Spring     | 1999-2018          | 8%          | 0.044             | Increasing trend |
|        | Summer     | 1961-1976         | 5%          | -0.097            | Decreasing trend |
|        |            | 1999-2018         | 6%          | 0.075             | Increasing trend |
|        | Autumn     | 1997-2018         | 3%          | 0.067             | Increasing trend |

3. Conclusions

The current study proves that in Constanta, in the last more than 58 years, the extreme temperatures’ augmentation is not an exception from the global warming. Normally, due the natural and anthropogenic activities, there are variations from a season to another, from year to another, but, doubtless, there is an overall increasing tendency of the mean temperature at the annual and seasonal scales. Based on the available dataset, a rough prediction of the future temperature has been made, but a complete and accurate image of the global warming effects requires the correlation between the extreme temperatures with other parameters as precipitation, solar radiation, sunshine duration, snow depth or greenhouse gases.

The study of the climate change is a highly difficult task that involves complex measurements, methods and models. Statistical methods used on the available data help to understand better the evolution of
climate and estimate the impact on the humanity. In fact, the outcomes of these analyses should converge in taking corrective actions in curving the disastrous effects of the global warming. The governments of many countries have recognized the serious threat of the climate change to the environment and humanity and have accepted that some immediate measures must be implemented. They signed the agreement of the Paris United Nations Climate Change Conference from 2015 [30] and began adopting it within their legal systems. An important target is pursuing efforts to limit the temperature increase to 1.5°C above the pre-industrial levels. This limitation will slow down the catastrophic consequences of damaging the environment and preserve what we have for the next generations.

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