INFLUENCE OF VARIABILITY OF THE EAST ATLANTIC OSCILLATION ON THE AIR TEMPERATURE IN MONTENEGRO

by

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In recent years, extreme air temperatures and other weather events are much more common in the territory of Montenegro. These events are result of changes in atmospheric circulation. The main objective of this paper is to examine the connection between air temperature parameters and variability of the East Atlantic Oscillation. The research in the framework of this theme was done using data from 23 meteorological stations for the period 1951-2010, and calculations were done for each season separately. The influence of the East Atlantic Oscillation was tested on 9 parameters of the air temperature in the territory of Montenegro, out of which 6 are climate indices. The obtained results showed that variability of the East Atlantic Oscillation influences the changes of air temperature in Montenegro, both in terms of average values and frequency of extreme events represented by climate indices.

Key words: temperature, extremes, East Atlantic Oscillation, Montenegro

Introduction

In the documents of the World Meteorological Organization [1, 2], as well as in the last report of the Intergovernmental Panel on Climate Change [3], and also in the works of numerous authors [4-11], it is shown that in many regions of the world, there is increase of the intensity and frequency of extreme weather events: maximum and minimum temperatures, droughts, floods, storms, heat waves, severe short rains, fires, etc. These events also include tornadoes that have been recorded on the Balkan Peninsula [12, 13].

Burić et al. [14] analysed the changes in the air temperature in Montenegro for the period 1951-2010 on seasonal and annual levels. Detailed analysis has shown that the most pronounced is a trend of increase of average summer temperature, and in almost all areas it is statistically significant. The increase of average spring temperature is somewhat lower and still significant at many important stations. However, in winter and autumn seasons changes of temperatures are insignificant. Moreover, the trend of winter average temperature is negative at 7 out of 23 stations and for autumn season at 11 stations. Similar results are obtained for average maximum and average minimum temperatures. For daily extremes, more frequently higher values of maximum and minimum daily temperatures occur in Mon-
In many works, it is emphasized that the dominant cause of air temperature increase in the second half of 20th and the beginning of 21st century is the anthropogenic factor, or increase of atmospheric concentration of CO2 and other greenhouse gases [3, 15-17]. Certainly, one of the main meteorological factors, and probably the most significant, which affects the weather is atmospheric circulation, or surface and upper-air circulation. Therefore, in recent studies the attention is given more to the influence of circulation factors [18-23], i.e., phenomena in the ocean-atmosphere system on global climate and climate of smaller territorial units.

Considering the previous, the main aim of this work is to investigate the connection between changes of temperature extremes and other parameters for Montenegro and indicators of variation of the East Atlantic Oscillation (EAO). The correlation was determined at the seasonal level, not for each month separately. The calculations at the monthly level and cyclical changes of the EAO could be used in the long-term weather forecast. However, it requires numerical modelling and a software for the long-term forecast.

The East Atlantic Oscillation

The EAO is one of the most important parts of the atmospheric circulation over the North Atlantic for all months. The indicator of fluctuation of the EAO is the EAO index*. Atmospheric-pressure centres that define the EA index are almost the same as for the North Atlantic Oscillation (NAO). The EAO represents the difference of the altitude of 500 hPa surfaces, with one centre about 55 °N and 20-30 °W and other of opposite sign between 25-35 °N and 0-10 °W [24]. Thus, both centres of the EAO are south of the NAO centres, although the EAO is structurally similar to the NAO.

For this reason the EAO is often interpreted as the NAO shifted south. However, the south centre is strongly associated with subtropical field of high pressure. This subtropical connection makes the EAO different from the NAO. Both oscillations represent a natural variability, but some consider [25] that they are influenced by the anthropogenic greenhouse effect.

The extremely cold winter of 2010 in Western Europe, with the coldest December in Great Britain in the last 100 years, cannot be explained by the NAO alone. Consideration of other atmospheric tele-connection patterns has shown that the EAO, to a large extent, can explain why December of 2010 was so cold, and that after the NAO, it is the most significant climate modifier in the North Atlantic [26].

The positive phase of this oscillation is characterized by a lower height of the isobaric surface at higher geographical latitudes, and a higher height in subtropical regions, compared to normal. When the height anomalies are opposite, the EAO is in the negative phase. The EAO positive regime brings higher air temperatures in Europe during all months, and lower temperatures in January-May in the south part of the USA and during July-October in the central part of North America. In terms of precipitation, the positive phase contributes to higher amounts in the North Europe, and lower in the South Europe**.

* ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/ea_index.tim
** http://www.cpc.ncep.noaa.gov/data/teledoc/ea.shtml
Data and methodology

For the purpose of this study, the air temperature data from 23 meteorological stations have been used, fig. 1, for the period 1951-2010. Examination of series homogeneity and filling the missing data was done using MASH v3.02. This method is developed by the Hungarian Meteorological Service [27], and its use is recommended by the World Meteorological Organization.

Figure 1. Location and elevation of analyzed meteorological stations

In total 9 parameters of air temperature have been used, tab. 1, for examination of the connection with the EAO. Of these, 6 indices are related to the temperature extremes ($SU$, $Tn90p$, $Tx90p$, $FD$, $Tx10p$, and $Tn10p$). All indices are defined in terms of the number of days with maximum temperature, $Tx$, and minimum temperature, $Tn$, above/below an absolute threshold or percentile. Beside climate indices, which are undertaken from the list of 27 indices, connection is examined and with average, $Tsr$, average maximum, $Txsr$, and average minimum, $Tnsr$, air temperature.

Percentile thresholds are calculated for each calendar day during the period 1961-1990, from 5 day window, whose central member is a given day. In this way, 150 data for each calendar day [2] are obtained. Therefore, for each station 365 (366) thresholds is calculated.

In recent years, the indicators of atmospheric circulation change are increasingly used to explain a part of the climate variability at different temporal and spatial scales [28].
In this study, the connection between fluctuation of the EAO and change of the air temperature in Montenegro, for the period 1951-2010 is examined. The Pearson correlation coefficient was calculated and significance of the connection was tested using Student's test, on the levels 90% and 95% (0.10 and 0.05). The connection was tested for each station separately, and correlation results are shown as average for the area of Montenegro as a whole.

**Results and discussion**

In Montenegro, connection between summer values of the EAO index and all other discussed temperature parameters, is statistically significant, mainly on the 99% confidence level. For this season, the absolute value of the correlation coefficients are between 0.50 and 0.70, which means that the EAO in the period 1951-2010 had a strong influence on inter-annual fluctuation of discussed summer temperature parameters.

For winter season, Tsr, Txsr, and Tx10p at each station shows significant correlation, as for Tx90p (with exception of one station – Cetinje) and mainly on 99% confidence level. In most places the connection between the EAO with Tnsr, FD, Tx10p, and Tn10p is significant.

The connection between spring EAO and discussed temperature parameters at most places is not significant, only for FD and Tn10p. With all other spring parameters of temperature (Tsr, Txsr, Tnsr, Tx10p, Tx90p, SU, and Tn90p) coefficient values satisfy the conditions of the significance test, mostly on 99% of confidence level. In autumn season smaller number of temperature parameters shows significant connection with the EAO index: Txsr and Tx10p mostly in all places (on 22 out of 23 stations), and Tn10p at 14 stations.

When Montenegro is seen as a unique field, based on the statistics of averaging in space and time, summer temperature parameters shows the best connection with the EAO. Even though, the coefficient values are something lower, connection is significant and for all winter temperature parameters. In spring season significant conditions do not meet only a number of cold nights (Tn10p), and in autumn season a number of frost days and warm nights (FD and Tn90p), till other temperature parameters satisfy the significance conditions, tab. 2.

The calculation showed that for all months there is an increasing trend of the EAO index for the period 1951-2010, and therefore also on seasonal level. Consequently, there is an indirect correlation between the EAO index and cold indices (FD, Tn10p, and Tx10p),

### Table 1. List of used indicators of air temperature

<table>
<thead>
<tr>
<th>Index</th>
<th>Unit</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD</td>
<td>No. of days</td>
<td>Number of frost days in time unit – daily Tn &lt; 0 °C</td>
</tr>
<tr>
<td>Tx10p</td>
<td>No. of days</td>
<td>Number of cold days – daily Tx &lt; 10th percentile</td>
</tr>
<tr>
<td>Tn10p</td>
<td>No. of days</td>
<td>Number of cold nights – daily Tn &lt; 10th percentile</td>
</tr>
<tr>
<td>SU</td>
<td>No. of days</td>
<td>Number of summer days – daily Tx &gt; 25 °C</td>
</tr>
<tr>
<td>Tx90p</td>
<td>No. of days</td>
<td>Number of warm days – daily Tx &gt; 90th percentile</td>
</tr>
<tr>
<td>Tn90p</td>
<td>No. of days</td>
<td>Number of warm nights – daily Tn &gt; 90th percentile</td>
</tr>
<tr>
<td>Tsr</td>
<td>[°C]</td>
<td>Average air temperature</td>
</tr>
<tr>
<td>Txsr</td>
<td>[°C]</td>
<td>Average maximum air temperature</td>
</tr>
<tr>
<td>Tnsr</td>
<td>[°C]</td>
<td>Average minimum air temperature</td>
</tr>
</tbody>
</table>
while for other temperature parameters there is phase synchrony, which is the most obvious for summer season (fig. 2).

Based on data of the NASA-GISS network, when North hemisphere is seen as a whole, connection between annual values of the EAO index and surface temperature is better than for Montenegro ($r = 0.70$), and it is significant for the areas of Europe and the Balkans (about 0.53).

Unkašević and Tošić discussed trends of six climate indices, based on maximum and minimum daily temperatures for the period 1949-2009. Analysis of extreme temperature indices showed that Serbian climate has a tendency to become warmer in the last 61 years. The most significant trends were obtained for the summer season. The authors have determined that the EAO is dominant during the winter, spring and summer, while in the autumn East Atlantic-West Russian (EAWR) index is produced. A strong signal was obtained between winter temperature extremes in Serbia and the NAO.

Nesterov found the connection between the EAO and NAO and temperature regime of the European Atlantic region, especially in the period 1996-2007. Knežević et al. investigated the influence of the EAO on the minimal temperature in Serbia on the basis of the data from eight meteorological stations. The correlations were calculated on monthly and seasonal level for the period 1950-2009. The authors determined negative correlation between the EAO index and the number of cold nights (Tn10p) and frost days (FD), and positive correlation between the EAO index and the number of warm nights (Tn90p) and tropical nights for all seasons. The highest correlation was determined between the EAO index and Tn90p.

**Conclusions**

In Montenegro, maximum and minimum daily temperatures which have warmer values are increasingly occurring. This means that there is an increase of frequency of daily temperature extremes in positive sense (towards warmer conditions). In most of the cases the trend of temperature extremes is significant, especially during the summer and spring season [14].

Most scientists believe that global warming is a consequence of anthropogenic influences. Others consider that it is strongly influenced by natural factors influencing the temperature, precipitation, and other elements, and there are different opinions about the balance of natural and anthropogenic factors on the climate [32]. The energy influence of certain factors differs spatially and temporally. An additional complication for estimation of certain

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**Table 2. Correlation matrix between the EAO indices and temperature parameters on the seasonal level for the Montenegro territory as a whole, for the period 1951-2010**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsr</td>
<td>0.46**</td>
<td>0.47**</td>
<td>0.63**</td>
<td>0.26*</td>
</tr>
<tr>
<td>Tnsr</td>
<td>0.42**</td>
<td>0.41**</td>
<td>0.62**</td>
<td>0.30*</td>
</tr>
<tr>
<td>Txsr</td>
<td>0.60**</td>
<td>0.51**</td>
<td>0.65**</td>
<td>0.41**</td>
</tr>
<tr>
<td>FD</td>
<td>-0.39**</td>
<td>-0.26*</td>
<td>–</td>
<td>-0.18</td>
</tr>
<tr>
<td>Tn10p</td>
<td>-0.32*</td>
<td>-0.75</td>
<td>-0.49**</td>
<td>-0.37**</td>
</tr>
<tr>
<td>Tn90p</td>
<td>0.38**</td>
<td>0.52**</td>
<td>0.63**</td>
<td>0.25</td>
</tr>
<tr>
<td>Tx10p</td>
<td>-0.46**</td>
<td>-0.41**</td>
<td>-0.60**</td>
<td>-0.41**</td>
</tr>
<tr>
<td>Tx90p</td>
<td>0.58**</td>
<td>0.46**</td>
<td>0.60**</td>
<td>0.28*</td>
</tr>
<tr>
<td>SU</td>
<td>–</td>
<td>0.39**</td>
<td>0.66**</td>
<td>0.30*</td>
</tr>
</tbody>
</table>

* Statistical significance for $\alpha = 0.05$
** Statistical significance for $\alpha = 0.01$

* http://www.co2science.org/data/temperatures/temps_plot.php
influences on temperature, precipitation, and other elements, is feedback effects, as well as the fact that there is almost no linear dependence between some variables (climate elements and certain factors).

The results of research on the connection between changes of air temperature in Montenegro and fluctuation of EAO, for period of 60 years (1951-2010) are given in this study. Estimation of the EAO influence for given 60-years period, shows that variability of this atmospheric pattern influence on tested temperature parameters in Montenegro, as for
seasonal average values, as well as for the frequency of extreme events shown through climate indices. The best connection was obtained for summer season – correlation coefficient is around 0.50-0.70. Even though the correlation values are lower than for summer season, the connection is statistically significant and for other seasons. This means that the EAO variability and fluctuation of the air temperature on Montenegro territory to a large degree occurs during whole year. According to our estimates, the EAO has the highest influence on the considered temperature parameters during summer. Strictly statistically, during the summer season, the influence of EAO on the temperature fluctuations is estimated between 30% and 40%. During the other seasons, the effect of EAO is lower. It ranges between 5% (autumn) and 20% (winter and spring). These estimations should be considered approximate, since it is certain that variations in other oscillations also have their impact, such as, for example, the NAO and the Mediterranean oscillation, but it should be confirmed in further research. Therefore, the focus in this research was on the impact of the EAO on the parameters of the air temperature in Montenegro.

References


[18] Ducić, V., Radovanović, M., Climate of Serbia (in Serbian), Zavod za Udžbenike i Nastavna Sredstva, Belgrade, 2005


