ATLANTIC MULTI-DECADAL OSCILLATION AND CHANGES OF SUMMER AIR TEMPERATURE IN MONTENEGRO

by

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The paper has examined the impact of variations of Atlantic multidecadal oscillation on the change in air temperature during the summer season on the territory of Montenegro. Starting from the fact that in recent years more and more extreme weather events occur, as well as from the intention to comprehensively consider the temperature conditions in the territory of Montenegro, first analysis is of changes in air temperature in 8 parameters, of which 5 climate indices; connections with Atlantic multidecadal oscillation have also been analyzed. To study changes in temperature extreme indexes proposed by the WMO CCL/CLIVAR are used. Research within the listed topics was realized using data from 23 meteorological stations for the period 1951-2010 and the calculations are done for the summer season. The results show that there is increased number of maximum and minimum daily temperatures of warmer value. The impact assessment Atlantic multidecadal oscillation, teleconnection pattern that is quite distant, showed that its variability affects changes in summer temperatures in Montenegro, both in terms of mean values, and the frequency of extreme actions presented by climate indices.

Key words: *temperature, extremes, the Atlantic multidecadal oscillation, Montenegro.*

Introduction

In many regions of the world changes were registered in the intensity and frequency of extreme weather events, such as high and low temperatures, drought, floods, storms, heat waves, strong short-term rains, fires, *etc*., causing great casualties and material damage [1]. Because of the fact that the temperature and precipitation extremes can cause great damage to the natural environment and human life and work, they are the subject of many research studies [2-4]. Extreme weather events are caused by current synoptic situation, *i. e.* circulating reasons, but many believe that the positive trend is the consequence of global warming. Thus Frich *et al*. [5] point out that the trend of changes in indices of temperature on the planet is the consequence of global warming. Klein-Tank and Konnen [6] have come to similar results for Europe. The authors believe that the trend of change in the index in Europe, relating to the minimum temperature, is determined by global warming.

Trigo *et al*. [7] point out that the Mediterranean in the 20th century was marked by positive temperature trends in all seasons, especially during winter and summer. The general opin-

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ion is that in the Mediterranean region warmer conditions have a negative impact on the environment and further exacerbate the economic situation [8-10].

Using data on the maximum temperature with 3 meteorological stations in Serbia, Unkašević and Tošić [11] found that the hottest summer in terms of intensity and duration of warm waves recorded 1951-1952, then 1987-1998 (particularly 1994), and 2000-2007. Unkašević and Tošić [12] point out that the cause of the warm waves during July 2007 was the current synoptic situation or the influx of hot and dry air from North Africa to Southeast Europe and adiabatic heating.

Atlantic Multidecadal Oscillation (several decades) or abbreviated AMO is a natural variation in surface water temperature of the North Atlantic, and therefore the circulation changes both in the ocean and in the atmosphere. This oceanic component system disorder ocean-atmosphere has a strong influence on the temperature in the northern part of the Atlantic basin, *i. e.* on the territory of Europe and North America [13]. The question of the causes of AMO and mechanism of transmission influence is still not resolved, but probably a connection between meteorological elements and this is realized indirectly – through atmospheric circulation.

Schlesinger and Ramankutty [14] were among the first to point out that the changes of surface water temperature in the North Atlantic have influence even on the global temperature. They found that fluctuations in global temperature can extract cycles lasting 65-70 years. Finally they conclude that these cycles are in relation to 50-88 fluctuations of surface water temperature in the northern part of the Atlantic Ocean, or the AMO. Based on historical records, using the spectral analysis, the authors believe that these oscillations can be predicted and thus the variability of the ocean-atmosphere system.

The AMO warm phase, in addition to leading to more air temperatures than usual in some areas, causes more frequent and longer-lasting droughts, for example in the southwestern region and the Midwest in the United States [15]. Biondi *et al*. [16] find that the AMO, and Pacific Decadal Oscillation (PDO), has an impact on air temperature in the higher latitudes, as well as at the global level.

Delworth and Mann [17] point out that the AMO natural oscillatory phenomenon that implies a change of surface water temperature (hereinafter referred to as Sea surface temperature – SST) in the North Atlantic is not related to anthropogenic influence. The authors point out that the average cycle is about 70 years, and warm and cold phases from 20 to 40 years.

It was found that there is a link between AMO and tropical storms in the southeast United States. Historical records indicate that the big Atlantic hurricanes were more common during the more than average surface water temperatures in the North Atlantic, *i. e.* during the warm phase of the AMO, which normally last longer than during the cold phases [13, 18, 19]

During warm (positive) AMO phase, summer rains are below average in most parts of the USA, while rainfall is increased in the Sahel region in Africa in the aforementioned season. This phase of the AMO causes higher summer temperatures in the eastern USA and in Central Europe [18, 20].

Compo and Sardeshmukh [21] state: *There is evidence that the increase in global air temperature over the last decades is largely caused by warming oceans, rather than as a direct response to the increase in greenhouse gases (GHG) above the Earth? Simulation models of the IPCC underestimate natural Decadal variability of SST*.

The AMO refers to the variation of ocean circulation, which involves the movement of warm surface water from the equatorial to the northern latitudes of the Atlantic, its cooling along the way and sinking into deeper layers (part of the thermohaline circulation). During the warm AMO phase, thermohaline circulation is faster or greater amount of equatorial water moves toward higher latitudes of the Atlantic. The AMO cold phase slows the thermohaline circulation, so the inflow of warm equatorial waters is slower in the high latitudes of the North Atlantic.

Henk *et al*. [22] demonstrated the existence of expressed the AMO signal changes of surface water temperature in the polar latitudes of the Atlantic. Other researchers have found that there is a strong link between AMO and air and water temperatures of the Atlantic polar. The first research on the impact of AMO on climate of Montenegro was done by Burić [3].

Data and methodology

For the purposes of this study we used data on air temperature from 23 meteorological stations (tab. 1) for the period 1951-2010. Testing of homogeneity sequences and filling in missing data was done by means MASH v3.02. This method was developed by the Hungarian Meteorological Service [23], and its use is recommended by the World Meteorological Organization.

Table 1. Co-ordinates of meteorological stations included in the analysis

Station	Latitude (N)	Longitude (E)	Altitude (masl)
Ulcinj	41º55’	19º13’	4
Bar	42º6’	19º5’	6
Budva	42º17’	18º50’	2
Tivat	42º24’	18º44’	5
Kotor	42º26’	18º46’	1
H. Novi	42º27’	18º33’	10
Virpazar	42º14’	19º5’	14
Golubovci	42º22’	19º15’	33
Podgorica	42º26’	19º16’	49
Danilovgrad	42º33’	19º6’	53
Cetinje	42º23’	18º56’	64
Crkvice	42º34’	18º38’	937
Grahovo	42º39’	18º40’	695
Velimlje	42º49’	18º38’	833
Niksic	42º46’	18º57’	647
Krstac	43º0’	18º42’	1017
Kolasin	42º50’	19º31’	944
Plav	42º36’	19º56’	933
Rozaje	42º51’	20º10’	1012
Berane	42º50’	19º53’	691
B. Polje	43º2’	19º44’	606
Zabljak	43º9’	19º7’	1450
Pljevlja	43º21’	19º21’	784

In this paper, analyzed temperature extremes are based on five indices, three of which are hot (*SU*, *Tn90p,* and *Tx90p*), and two cold (*Tx10p* and *Tn10p*). All indexes are defined in terms of number of days with maximum (*Tx*) and minimum (*Tn*) temperature above/below the thresholds of absolute or percentile range. In addition to climate indices, which are taken from the list of 27 indices of average (*TSR*), mean maximum (*Txsr*) and mean minimum (*Tnsr*) temperature were analyzed. For the purposes of this paper, a total of 8 indicators of air temperature change were considered (tab. 2) during the summer season. The percentile range is calculated for each calendar day during the period 1961-1990 from a 5-day window whose central member is a given day. In this way 150 data for each calendar day are calculated [24]. Thus, 365 (366) thresholds are calculated for each cell.

Table 2. List of indicators used for air temperature

No.	Index	Unit	Definition
1	*Tsr*	ºC	Mean air temperature
2	*Txsr*	ºC	Mean maximum air temperature
3	*Tnsr*	ºC	Mean minimum air temperature
4	*Tx10p*	No of days	The number of cold days – daily *Tx* <10th percentile
5	*Tn10p*	No of days	Number of cold nights – daily *Tn* <10th percentile
6	*SU*	No of days	Number of summer days in the unit of time – daily *Tx*> 25 ºC
7	*Tx90p*	No of days	Number of hot days – daily *Tx*> 90th percentile
8	*Tn90p*	No of days	Number of hot nights – daily *TN*> 90th percentile

The trend is calculated using Sen's slope estimates, and its significance was tested by Men-Kendall test. Analysis of trends in ETCCDI workshop (Expert Team on Climate Change Detection and Indices) is based precisely on the use of these non-parametric methods [25], and their main advantage over parametric methods (*e. g.* Equation least square and t test) is that they do not require affiliation to a particular series of distribution [26-29]. To determine the connection Pearson correlation coefficient (r) is calculated and significance was tested using Student test, at the level of 90% and 95% ($\alpha = 0.10$ and 0.05). The connection is tested for each station separately.

The AMO fluctuations indicator is AMO index. This index is defined as a standardized deviation of the average surface temperature of the Atlantic between the equator and 75º N compared to the base period of 1951-2000. Positive values of this indicator point to the warm phase of the AMO, negative points to variation in the cold. For the purposes of the paper the monthly values of AMO indices were used. They are available on the website of the US Agency for National Oceanic and Atmospheric Administration (NOAA).

Results and Discussion

A statistically significant upward trend in average summer temperatures (*TSR*) was registered in 18 of the 23 stations. The smallest and insignificant changes in mean summer temperatures were obtained for the south-western part of the country, while in other regions significant positive tendencies. There also was increase in mean maximum (*Txsr*) and the mean minimum (*Tnsr*) temperature significant in a larger medium of Montenegro. The number of cold days (*Tx10p*) and cold nights (*Tn10p*) decreases at this time of year, and is important in the southern regions of the country, or at 16 stations (tab. 3). All analyzed cells showed a trend increase in the number of days with $Tx > 25$ ºC (*SU*), a positive tendency is significant almost for the entire territory of Montenegro. Calculations trend for the period 1951-2010, showed that in all cells is present tendency to increase the number of warm nights (*Tn90p*) and insignificant was only at the two stations. During three summer months there was a significant increase in the number of hot days (*Tx90p*) on the whole territory of Montenegro. Thus, all considered indices speak in favor of warmer summers in Montenegro.

Table 3. Trend parameters of air temperature for the summer season in the period 1951-2010

	ºC/decades			No of days/decades				
Station	*Tsr*	*Txsr*	*Tnsr*	*Tx10p*	*Tn10p*	*SU*	*Tx90p*	*Tn90p*
Ulcinj	0.22***	0.18*	0.17*	–0.3	–0.3	0.4	2.0***	2.0**
Bar	0.31***	0.35***	0.37***	–0.8**	–1.5***	1.9**	4.3***	3.9***
Budva	0.36***	0.35***	0.43***	–1.0**	–1.7***	1.6**	3.6***	4.0***
Tivat	0.10	0.37$^+$	0.09$^+$	–0.9**	0.0	0.8*	4.4***	1.2**
Kotor	0.11$^+$	0.32*	0.16*	–0.5	–0.4	0.7$^+$	3.7***	1.8**
H. Novi	0.14*	0.11***	0.25***	0.0	–0.6$^+$	0.7$^+$	1.5*	2.9***
Virpazar	–0.11	0.29**	0.21**	–0.8**	–0.9**	0.7*	2.2**	1.0$^+$
Golubovci	0.26**	0.32**	0.21**	–0.6*	–1.1**	0.9*	3.1***	1.8**
Podgorica	0.27**	0.34**	0.22**	–0.5$^+$	–0.6$^+$	0.6$^+$	3.6***	2.3**
Danilovgrad	0.11	0.34***	0.25***	0.0	–0.6$^+$	0.4	3.6***	2.5**
Cetinje	0.06	0.45***	0.11	–0.6$^+$	0.3	3.3***	3.6***	1.7**
Crkvice	0.17*	0.44***	0.12	–0.7$^+$	0.0	5.0***	4.1***	1.3
Grahovo	0.11	0.22	0.03	–0.7$^+$	0.5	2.0*	1.9**	0.9
Velimlje	0.19$^+$	0.26*	0.20*	–0.2	–0.5$^+$	2.4*	2.4**	3.0*
Niksic	0.25**	0.30***	0.26***	0.0	–0.9*	2.3**	2.9***	2.5***
Krstac	0.14$^+$	0.25*	0.17*	0.0	0.0	3.0**	2.9***	2.3**
Kolasin	0.29***	0.20***	0.26***	0.0	–1.0**	2.8*	2.7***	2.5***
Plav	0.39***	0.39***	0.49***	–0.5$^+$	–2.4***	3.1**	2.7***	3.3***
Rozaje	0.33***	0.39***	0.63***	0.0	–1.3***	3.2**	2.9***	6.7***
Berane	0.33***	0.46***	0.39**	–0.6*	–1.1***	3.3***	3.6***	3.6***
B. Polje	0.33**	0.23***	0.44***	–0.2	–1.7***	1.5*	2.0**	3.9***
Zabljak	0.28**	0.32***	0.34***	–0.3	–1.0**	1.6**	2.4**	2.9***
Pljevlja	0.28**	0.27***	0.35***	–0.3	–1.4***	2.2**	2.3**	2.7***

The significance of the trend on the level of: $^+\alpha = 0.1$; * α=0.05; ** α= 0.01; *** α = 0.001

Calculations of correlation coefficients between the AMO index and parameters of air temperature in Montenegro gave statistically significant results with nearly all analyzed parameters of temperature for the summer season, mainly at the level of confidence of 99%. For the period 1951-2010, almost all observed cells show a significant relationship between summer value of AMO index *Tsr*, *Tnsr*, *Txsr*, *Tn90p*, *Tx90p*, are *Tn10p* (tab. 4).

Table 4. Matrix of correlation between summer temperature parameters in Montenegro and AMO for the period 1951-2010.

Summer	AMO							
Station	*Tsr*	*Tnsr*	*Txsr*	*Tn10p*	*Tn90p*	*Tx10p*	*Tx90p*	*SU*
Ulcinj	0.46*	0.34**	0.33**	–0.19	0.33**	–0.22	0.32**	0.25
Bar	0.54*	0.54*	0.54*	–0.36*	0.55*	–0.47*	0.51*	0.52*
Budva	0.43*	0.35*	0.49*	–0.15	0.42*	–0.43*	0.47*	0.35*
Tivat	0.40*	0.33**	0.48*	–0.25	0.45*	–0.32**	0.49*	0.30**
Kotor	0.45*	0.36*	0.42*	–0.26**	0.41*	–0.24	0.42*	0.30**
H. Novi	0.50*	0.57*	0.29**	–0.40*	0.55*	–0.22	0.32**	0.29**
Virpazar	0.35*	0.35*	0.45*	–0.29**	0.20	–0.30**	0.51*	0.33**
Golubovci	0.46*	0.31**	0.32**	–0.11	0.46*	–0.06	0.49*	0.05
Podgorica	0.46*	0.45*	0.46*	–0.27**	0.47*	–0.26**	0.51*	0.23
Danilovgrad	0.44*	0.51*	0.42*	–0.37*	0.47*	–0.14	0.50*	0.17
Cetinje	0.48*	0.27**	0.38*	–0.25	0.18	–0.19	0.43*	0.41*
Crkvice	0.57*	0.54*	0.44*	–0.37*	0.54*	–0.08	0.54*	0.44*
Grahovo	0.50*	0.24	0.24	–0.12	0.24	–0.08	0.33**	0.30**
Velimlje	0.47*	0.45*	0.39*	–0.26**	0.47*	–0.13	0.42*	0.41*
Niksic	0.48*	0.42*	0.42*	–0.24	0.53*	–0.22	0.45*	0.44*
Krstac	0.40*	0.36*	0.36*	–0.15	0.38*	–0.12	0.43*	0.34**
Kolasin	0.55*	0.34**	0.40*	–0.21	0.44*	–0.07	0.47*	0.41*
Plav	0.54*	0.38*	0.44*	–0.22	0.45*	–0.20	0.45*	0.44*
Rozaje	0.54*	0.50*	0.44*	–0.38*	0.53*	–0.21	0.45*	0.42*
Berane	0.56*	0.54*	0.48*	–0.42*	0.56*	–0.26**	0.53*	0.46*
B. Polje	0.57*	0.35*	0.38*	–0.19	0.48*	–0.13	0.47*	0.37*
Zabljak	0.56*	0.38*	0.43*	–0.20	0.47*	–0.26**	0.45*	0.37*
Pljevlja	0.54*	0.47*	0.42*	–0.37*	0.50*	–0.15	0.46*	0.39*

The statistical significance of: * $\alpha = 0.01$; ** $\alpha = 0.05$

The existence of stochastic stronger links between temperature and AMO supports the sign of the correlation. Therefore, the calculated trend of AMO index is for all seasons. The results indicate the most pronounced upward trend in summer AMO index values (increase of the surface water temperature of the North Atlantic) and slightly less positive trend on an annual basis. It was the greatest increase of summer temperatures that is the strongest link between the AMO index and temperature parameters for the summer season. In other words, in the summer season there is most pronounced upward trend in AMO index in the observed 60-year period, it is expected that hot indicators of temperature rise and cold decline. Therefore, the antiphase synchronicity is evident between AMO and cold index (*Tn10p* and *Tx10p*). With other temperature parameters which obtained significant relationship there is a direct correlation (phase synchronicity).

In the introductory the mentioned articles indicate that AMO has an impact on global temperatures. In order to test this, we examined the relationship between AMO and global air temperature and the northern hemisphere. Our calculations indicate and confirm that there is a strong signal to the global AMO air temperature, especially in the last 30-year period. Correlation coefficients between different sets of global data are larger than for Montenegro. For the period 1951-2008, the coefficient of correlation between global temperatures by GHCN and HadCRUT3 data and AMO index is 0.56 or 0.53. Variations in global temperature NASAGISS networks, which are given in relation to the period 1951-1980, are available for 2009 and 2010. The correlation between this set (NASAGISS) and AMO index is 0.55 for the period 1951-2010. For the period 1981-2008 (GHCN and HadCRUT3), and 1981-2010 (NASAGISS), the values of correlation coefficients are 0.89, 0.95 and 0.90. For longer and shorter periods relationship is significant at 99% level of confidence. The rising trend in AMO index and terrestrial global annual mean temperature is significant at all levels of risk of hypothesis acceptance.

Correlation of AMO index with a temperature was examined for the northern hemisphere. In this case the connection is stronger than at the global level, which is logical, because this phenomenon is related to the North Atlantic region. For the period 1951-2010 the value of *r* (the correlation coefficient) between AMO and temperatures for the northern hemisphere, the NASAGISS data, is 0.68, while for the period 1981-2010 the correlation is 0.91. According to data from the MSU network (in the first 8 km troposphere) for the northern hemisphere, there was examined the relationship with the high-altitude temperatures for the period 1981-2009. The value of the correlation coefficient is 0.92. A clear phase synchronicity between changes AMO and ground and altitude temperatures for the northern hemisphere shows a graphic (fig. 1). Statistical significant portion of fluctuations in mean annual near-surface temperature and height above the northern hemisphere can be explained by changes in AMO index. Thus, a clear phase synchronicity, significant correlation coefficient value of the coefficient of determination (about 83%) and approximately the same slope of the trend, undoubtedly show that there is a link between temperature and AMO, and not just for the northern hemisphere, but also at the global level. Based on these results, it could be concluded that these fluctuations have an impact on long-periodic component, *i. e.* trend.

The main indicator of global warming is an increase in air temperature during the 20th century, and especially since the late 1970s. Foster and Rahmstorf [30] analyzed changes in global temperature, using data from three terrestrial networks (NASA/GISS, NOAA/NCDC and HadCRU) and two height (RSS and UAHMSU) for the period 1979-2010. All 5 data sets showed a trend of rising temperatures, both terrestrial and altitude. The rate of global warming in the period 1979-2010, as these authors point out, was predominantly under anthropogenic influence. In their opinion, the increase in the concentration of greenhouse gases affects the trend component, while the inter-annual temperature variations were determined by natural factors.

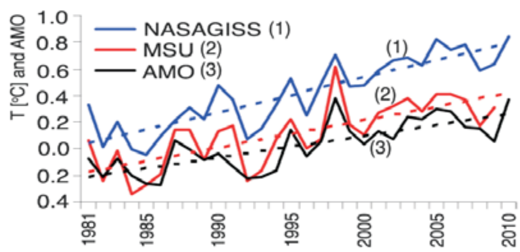

Figure 1. Changes in terrestrial (NASAGIS) and altitude temperatures (MSU) above the northern hemisphere as a whole, or the AMO index for the period 1981-2010

However, Tung and Zhou [31] point out that those natural factors have an impact on long-periodic component, primarily AMO. Using multiple linear regression analysis, their research shows that even in the industrial period, AMO may significantly explain episodes of warming and cooling. These ongoing for several decades the variability is not random, as evidenced by the reconstructed data for the previous three and a half centuries.

In favor of the dominance of natural factors in today's climate fluctuations are also studies of Muller *et al*. [32]. Considering the influence of AMO in global temperatures, the authors conclude that the variability of thermohaline circulation has a larger role than previously thought and that models would need to take into account.

It is obvious that there are contradictions about the impact of natural and anthropogenic factors on climate [33]. Energy influence of individual factors varies spatially and temporally. An additional complication assessment of individual impacts on temperature, precipitation and other is a feedback effect, and the fact that there is almost no linear relationship between the variables (climatic elements and individual factors). We think that is wrong suspicion that AMO is not the cause (in part), but rather a consequence of warming on Earth. If so, then it would be expected that there is a certain delay compared to global temperature, but that displacement is not observed.

In any case, one should always keep in mind that all phenomena on our planet are interrelated and interdependent. That is why research activities are increasingly focused on creating realistic computer model which links the global ocean and atmospheric phenomena and hence allow prediction of climate fluctuations. Based on the results obtained in this work, it can be reasonably concluded that the AMO has an impact on the temperature conditions in the territory of Montenegro. Also, the calculations showed that there is a strong signal of the Atlantic Multidecadal Oscillation and the global air temperature over the northern hemisphere, both in the ground and in the first 8 km of the troposphere.

Conclusions

Detailed analysis of 8 parameters of summer air temperature on the territory of Montenegro and their relationship with the Atlantic multidecadal oscillation (AMO) for the period 1951-2010, showed the following.

- Trend of average, mean maximum and mean minimum air temperature was a positive sign at all observed stations and generally is significant. Comparing the value trend of mean maximum and mean minimum temperatures for the observed 60-year period, the greater part of Montenegro is more intense than the maximum increase in the minimum temperature.
- Lowering the analysis of the daily extremes, on the territory of Montenegro is increasingly occurring maximum and minimum daily temperatures are warmer value. This means that there is an increase in the frequency of daily temperature extremes in the positive sense (to warmer conditions). In most cases the trend of temperature extremes is significant. In general, trend of warm temperature indices is higher than the cold, which is consistent with previous studies for the Montenegrin Coast.
- Based on the results obtained in this work, it can be reasonably concluded that the AMO has significant impact on the temperature conditions in the territory of Montenegro. Also, the calculations showed that there is a strong signal of the Atlantic multidecadal fluctuations in global temperature and the air above the northern hemisphere, both on the ground and in the first 8 km of the troposphere.

- It is obvious that there are contradictions about the impact of natural and anthropogenic factors on climate [33]. Energy influence of individual factors varies spatially and temporally. An additional complication assessment of individual impacts on temperature, precipitation and other is a feedback effect, and the fact that there is almost no linear relationship between the variables (climatic elements and individual factors). We think that is wrong suspicion that AMO is not the cause (in part), but rather a consequence of warming on Earth. If so, then it would be expected that there is a certain delay compared to global temperature, but that displacement is not observed.

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