HIATUS IN GLOBAL WARMING – THE EXAMPLE OF WATER TEMPERATURE OF THE DANUBE RIVER AT BOGOJEVO GAUGE (SERBIA)

by

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The research included trends in water temperature of the Danube River at Bogojevo gauge and surface air temperature at the nearby meteorological station Sombor, as well as an analysis of the results obtained in relation to the claims of the existence of the hiatus in global air temperature increase in the period 1998-2012. In the period 1961-2013, there was a statistically significant increase in the mean annual water temperature (0.039 °C per year), as well as all the average monthly values. However, with annual values for the period 1998-2013, there was a decrease. The longest periods of negative trend (27 years) were recorded for January and February. A high correlation was found between the surface air temperature and water temperature for all monthly and seasonal values. In the mean annual air temperature the presence of the hiatus is not observed, but a negative trend is recorded in March (32 years), December (43 years), and February (49 years). The highest correlations between water temperature and North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and Atlantic Multidecadal Oscillation (AMO) were obtained for the NAO in January (0.60), the AMO in autumn (0.52), and the NAO in winter (0.51). For surface air temperature, the highest correlations were registered for the AMO in summer (0.49) and the NAO in winter (0.42). The results indicate the dominant role of natural factors in the decrease of winter air temperature and water temperature of the Danube.

Key words: *hiatus, Danube, water temperature, air temperature, NAO, AMO*

Introduction

Multi-decadal long term trend of global warming since the end of the 19th century was detected on the basis of instrumental data. However, since the end of the 20th century, there is a hiatus in global warming. The word *hiatus* is mentioned in the report of the IPCC [1] to describe the trend in global temperatures since the end of the last decade of the 20th century. In the period

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1951-2012, a rise in temperature of 0.12 °C (0.08 to 0.14) per decade was recorded, while from the end of the 20th century a significantly lower increase has been recorded, depending on the year taken as the starting one. If 1997 is taken as the beginning of a series, an increase of 0.07 °C (–0.02 to +0.18) per decade is observed, while in the case of 1998, which is commonly referred to as the initial one, the increase is 0.05 ºC (–0.05 to +0.15) per decade [1]. Most of the research in this field has focussed on air temperature [2-11]. But there is a strong influence of air temperature on water temperature of rivers and streams [12, 13]. Accordingly, an increase in water temperature is recorded in many rivers. The increase of up to ~1 °C in mean river temperatures was recorded in Europe during the 20th century, but this trend was also due to some extreme hydrological events and also different human activities [14]. On the basis of river water temperature data (1990-2006) from 2,773 locations in England and Wales, it has been confirmed that the mean water temperature rise in this period was 0.03 °C per year (±0.002 °C). Positive trends were observed at 86% of the sites [15]. The hiatus in water temperature is recorded in the rivers of the United States [13]. In the period 1901-1990, an increase of 0.8 °C of the average monthly water temperature of the Danube River in Linz city was found [16]. Important factors that affect the water temperature are the thawing of snow and ice [17], as well as the anthropogenic factor [18]. In the period 1951-2006, there was an increase of about 0.1 °C per decade in the mean annual water temperature of the Danube in Vienna city. Significant increases were recorded for both winter and summer, while autumn and spring temperatures remained constant to quite a large degree [19]. The temperature of the Danube in Bratislava city in the period 1981-2005 increased by 0.6 °C compared to the previous 25 years. At the same time, the mean annual air temperature in Vienna increased by 0.8 °C. However, for the period 1931-2005 the trend was almost flat [20]. The temperature rise of the Danube has also been recorded in the period 1988-2005 [12]. Lovasz [21] determined the differences in the rising trends of the summer water temperature in Hungary (1951-2010): 0.08 °C during 60 years for the Danube section (378.6 km) and 1.1 °C years for the Tisza River section (572.3 km). Since the middle of 1960s, winters were milder for approximately ten years, but in following years there was almost stagnation. In the Eastern part of the Carpathian Basin, after remarkable positive trends back to the beginning of the 1980s, significant slowing down has been recorded since the early 1990s [21]. The research of the temperature trends (1960-2006) at 88 meteorological stations in the Upper Danube Basin showed the increase at a high rate (up to 0.8 °C per decade) of the summer temperature. The trends were highly significant for all investigated summer, spring and annual time series. Winter and spring temperature trends were positive, but in some time series, there was no significance at all and the trend values were smaller. Autumn temperature trends were mostly non-significant and the values were low (up to 0.3 °C per decade) and there were also several negative trends [22].

The aims of this research were to:
– investigate the trend of water temperature of the Danube in Serbia in the example of the hydrological station Bogojevo,
– research the influence of teleconnections on the water temperature, having in mind the influence on air temperature and precipitation in Serbia [23-25], and
– analyse the extent to which the results obtained are in accordance with the claims of the IPCC [1] about the existence of the hiatus in air temperature increase.

Data and methods

The data from the hydrological station Bogojevo (45°31' N, 19°04.9' E, 77.46 m a. s. l., and distance from the mouth of 1,367.25 km) include monthly, seasonal, and annual values of water temperature for the period 1961-2013. Missing data (less than 5%) were interpolated us-

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ing linear regressions based on the neighbouring hydrological station in Bezdan (45°51.3' N, 18° 51.9' E, 80.64 m a. s. l., distance from the mouth of 1,425.59 km) [26]. The hydrological stations are shown in fig. 1.

Figure 1. Surface water station network of regional hydrological station Novi Sad, with the locations of hydrological stations Bezdan (1) and Bogojevo (3) (source: Republic Hydrometeorological Service of Serbia)

The research used surface air temperature data of the closest weather station in city of Sombor (45°46' N, 19°09' E, 88 m a. s. l.) for the period 1949-2013 [27]. Based on Alexandersson test, it has been found that the data for air temperature of Sombor meteorological station are homogeneous [28].

The research also used teleconnection data: North Atlantic Oscillation (NAO) [29], Arctic Oscillation (AO) [30], and Atlantic Multidecadal Oscillation (AMO) [31].

The Pearson's correlation coefficient (*R*) was used in the correlation calculations. The method of least squares was used for the calculation of the trend. The trend was first calculated for the period 1999-2013 (the same length as the period 1998-2012, in which the report of the IPCC concluded that there was a hiatus), forwarded only for one year (2013) for which new data were available. Then, from the period 1999-2013, the calculation of the trend was extended by one year back (1998-2013, 1997-2013, *etc*.) as long as the sign of the trend was negative, as opposed to the expected temperature rise under the influence of enhanced greenhouse effect. In this way the hiatus in the trend of temperature is defined by the strictest criterion (decrease rather than stagnation) in the whole observed period. The significance of the correlations is determined from the table, and trends from the equation:

$$y = R\sqrt{(n-2)/1 - R^2} \tag{1}$$

where *R* is Pearson's correlation coefficient, R^2 – the coefficient of determination, and *n* – the length of series.

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Results

In the period 1961-2013 statistically significant increase was recorded in water temperature in all months, seasons, and annual values, which is in line with global changes in air temperature. The increase in mean annual water temperature is 0.039 °C per year. The largest increase was recorded in August (0.058 °C per year). Observed by seasons, the highest increase was recorded in summer (0.046 °C per year).

Table 1. Period (years) of decrease in the water temperature of the Danube (Bogojevo)*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Avg	Sep	Oct	Nov	Dec	Year	Wint.	Spr.	Sum.	Aut.
Start	1986	1986	1988	–	2000	1991	2001	1992	–	1990	2000	2000	1998	1988	1998	1992	1999
End	2013	2013	2013	–	2013	2013	2013	2013	–	2013	2013	2013	2013	2013	2013	2013	2013
No.	27	27	25	–	13	22	12	21	–	23	13	13	15	25	15	21	14

* Periods shorter than 10 years have not been taken into account, since the criteria of Roberts *et al*. [32] has been accepted

However, it has been observed for the annual values that during the period 1998-2013 there was a fall in temperature, similar to the occurrence of the hiatus. Moreover, at six months, the water temperature has decreased for more than 20 years (tab. 1). The maximum duration of the negative trend is registered in January and February (27 years). The trend values are not statistically significant, which is consistent with the applied research methodology for the last year backwards from which the trend is negative, for which the slope of the trend line is inevitably small and statistically insignificant. Observed by seasons, the longest period of hiatus is in winter (25 years). In summer, its length is 21 years. In spring it has lasted since 1998 (15 years), while in autumn the hiatus has been present from 1999.

The Pearson's correlation coefficient (R) with the air temperature at the meteorological station in Sombor showed the expected high values for all monthly and seasonal values, of statistical significance at $p = 0.01$.

In the period 1961-2013, a statistically significant increase in air temperature was recorded in six months, with the largest increase in January (0.0709 °C per year). Observed by seasons, summer only showed a statistically significant increase of 0.052 °C per year.

Table 2. Period (years) of decrease in the air temperature (Sombor)*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Avg	Sep	Oct	Nov	Dec	Year	Wint.	Spr.	Sum.	Aut.
Start	–	1964	1988	–	1993	1996	–	–	1981	1995	2000	1970	–	1988	1999	–	–
End	–	2013	2013	–	2013	2013	–	–	2013	2013	2013	2013	–	2013	2013	–	–
No.	–	49	25	–	20	17	–	–	32	18	13	43	–	25	14	–	–

* Periods shorter than 10 years have not been taken into account, since the criteria of Roberts *et al.* [32] has been accepted

The presence of hiatus is not indicated for annual values of surface air temperature in Sombor (fig. 2). However, it is present at seven months, of which at five it is longer than 20 years (tab. 2). In the period 1961-2013, the negative trend is recorded for the last 32 years in September, 43 in December and 49 in February. If we also take into account the data from the beginning of the measurement, then the negative trend in February has been present since 1957 (56 years), and in December since the first year of measurement – 64 years.

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The correlations with teleconnections were done in order to establish the cause of the unexpectedly long periods of negative trend in water temperature at Bogojevo hydrological station and surface air temperature at Sombor meteorological station (NAO, AO, and AMO).

The highest values of R for monthly water temperatures and teleconnection are obtained for the NAO (tab. 3). In the period December-March, R is all the time significant at $p = 0.01$, with a maximum in January ($R = 0.60$).

Figure 2. Linear trend of December air temperature in Sombor (1949-2013)

The AO values are slightly lower, and significant correlation occurs in 5 months, with a maximum R in September (0.42). With the AMO, the correlation coefficient is continuously significant in the period July-November, with a maximum in October ($R = 0.47$).
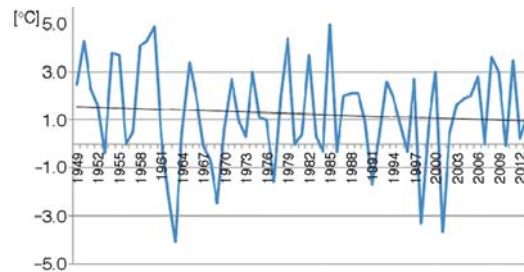
Table 3. Pearson's correlation coefficient between water temperatures of the Danube (Bogojevo) and teleconnections (NAO, AO, and AMO)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Avg	Sep	Oct	Nov	Dec
NAO	0.60**	0.37**	0.49**	0.05	–0.02	–0.24	0.06	0.08	0.09	–0.16	–0.05	0.37**
AO	0.37**	0.36**	0.35*	0.21	0.12	–0.27	0.16	0.35*	0.42**	–0.04	0.14	0.21
AMO	0.02	0.01	–0.03	0.11	0.21	0.26	0.38**	0.30*	0.29*	0.47**	0.35*	–0.06

* $p = 0.05$; ** $p = 0.01$

At seasonal values of the water temperature (tab. 4), R shows the highest value in autumn with the AMO, 0.52 (fig. 3), followed by the NAO in winter, 0.51 (fig. 4). Both R values are significant at $p = 0.01$. In winter and spring, R is significant with the AO, and in summer and autumn with the AMO. The effect of the AO ($R = 0.47$) and AMO ($R = 0.45$) is also significant for annual values at $p = 0.05$.

In case of seasonal values of air temperature, R shows the highest value in summer for the AMO ($R = 0.49$), then for winter for the NAO ($R = 0.42$). The influence of the AO ($R = 0.37$) and AMO ($R = 0.40$) is also significant for annual values at $p = 0.05$.

The matching of statistically significant values of the impact of teleconnection on air and water temperatures is observed for winter for the NAO, for spring for the AO,

Table 4. Pearson's correlation coefficient between water temperatures of the Danube – Bogojevo (T_w) and air temperature – Sombor (T_a) and teleconnections (NAO, AO, and AMO)

	NAO				
	Year	Winter	Spring	Summer	Autumn
T_a	0.12	0.42**	0.13	–0.28*	–0.14
T_w	0.22	0.51**	0.26	–0.14	–0.11
	AO				
	Year	Winter	Spring	Summer	Autumn
T_a	0.37**	0.26	0.39**	–0.02	–0.08
T_w	0.47**	0.34*	0.44**	0.06	0.17
	AMO				
	Year	Winter	Spring	Summer	Autumn
T_a	0.40**	–0.04	0.13	0.49**	0.32*
T_w	0.45**	0.01	0.15	0.42**	0.52**

* $p = 0.05$; ** $p = 0.01$

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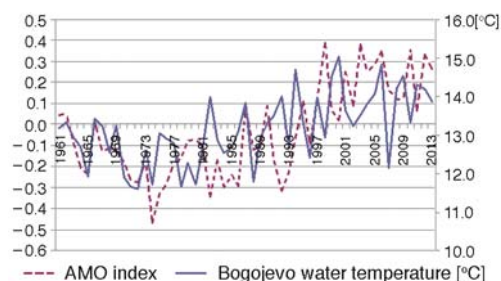
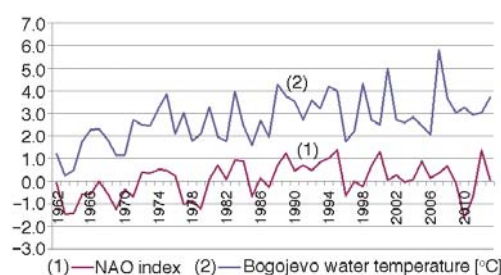**Figure 3. Autumn water temperature (Bogojevo) and AMO ($R = 0.52$)**

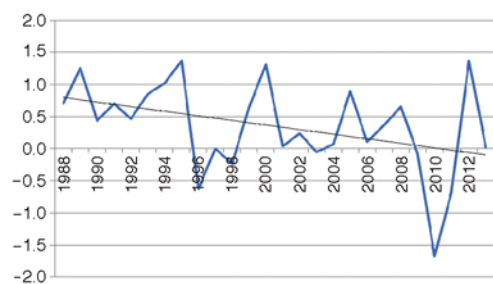**Figure 4. Winter water temperature (Bogojevo) and NAO ($R = 0.51$)**

Figure 5. Linear trend of NAO index (1988-2013)

and for summer and autumn for the AMO. In addition, the trend of the NAO index in winter season during the hiatus, which is for air and water temperatures of the same length (25 years), has also been negative, and statistically significant (fig. 5). It certainly confirms the claim that natural factors dominated the decrease of winter air temperatures in Sombor and consequently the Danube water in the last 25 years (1988-2013). After all, the change in temperature by a sign does not fit in the hypothesis of the dominance of the GHG impact.

Discussion

There is no doubt that there is a hiatus in water temperature of the Danube near Bogojevo and that this phenomenon is related to air temperature. Certain doubts also arise in relation to the length of the time series which could be considered a hiatus. According to Roberts *et al*. [32] the probability of a variability-driven 10-year hiatus is ~10%, but less than 1% for a 20-year hiatus. They also claim that the probability of continuing of existing 15-year hiatus for another five years is up to 25%. Santer *et al*. [33] emphasize that a single decade of observational temperature of lower troposphere data is not adequate for identifying an anthropogenic warming signal. For this purpose they suggest the use of temperature records of at least 17 years. McKitrick [34] confirmed trendless interval of 19 years duration at the end of the HadCRUT4 surface temperature series, and of 16-26 years in the lower troposphere. The use of a simple AR1 trend model suggests a shorter hiatus of 14-20 years, but is probably unreliable. *The simulations rule out (at the 95% level) zero trends for an interval of 15 years or more, suggesting that an observed absence of warming of this duration is needed to create a discrepancy with the expected present-day warming rate* [35].

The highest values of correlation for monthly water temperatures in the Danube in Bogojevo and teleconnections are obtained for the NAO. Webb and Nobilis [36] investigated the thermal regime of the Danube mainstream and found that correlations with the NAO were generally stronger for air than for water temperatures. Correlations were statistically significant for air temperatures in all cases except for the April-June quarter at all stations and the October-December period at Zell-am-See. The strongest correlations between air temperature and the NAO residuals were recorded for the January-March quarter. Marković, *et al*. [37] re-

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searched the long-term water temperature series from the Elbe and the Danube Rivers Basin. The statistical models based on air temperature, river discharge and the NAO Index successfully described the observed patterns in monthly and daily water temperatures. According to these models, air temperature variability describes more than 80% of the total water-temperature variability. The connection between the NAO and the temperature of rivers and streams has also been found in other areas, *e. g.* Wales [38].

The trend of winter values of the NAO during the hiatus and the water temperature in Bogojevo is negative and statistically significant, which is not in accordance with the models. In the report of the IPCC [1], the NAO response is being considered to anthropogenic forcing. Climate models are generally able to simulate the gross features of the NAO. Hori, *et al*. [39] noted that the NAO variability did not change substantially in the SRES-A1B and 20th century scenarios. Model simulations have underestimated the magnitude of the large positive trend from 1960-2000 in winter NAO observations, which now appears to be more likely due to natural variability rather than anthropogenic influences. Some studies have even considered NAO to be a source of natural variability that needs to be removed before detection and attribution of anthropogenic changes [40].

Recent multi-model studies of the NAO [39, 41-43] reconfirm the small positive response of boreal winter NAO indices to GHG forcing noted in earlier studies reported in AR4 [44-46]. Projected trends in wintertime NAO indices are generally found to have small amplitude compared to natural internal variations [47]. Furthermore, there is substantial variation in the NAO projections from different climate models. For example, one study found no significant NAO trends in two simulations with ECHAM4/OPYC3 [48], whereas another study found a strong positive trend in the NAO and the ECHAM5/MPI-OM SRES A1B simulations [49].

Conclusions

This paper analyses the trends of monthly and seasonal and annual water temperatures of the Danube in the hydrological station Bogojevo (45°31' N, 19°04.9' E, 77.46 m a. s. l.) and neighbouring weather station Sombor (45°46' N, 19 °09' E, 88 m a. s. l.). For annual values of water temperature it was observed that in the period 1998-2013 there was a fall in temperature, similar to the occurrence of the hiatus in global air temperature. At six months, the water temperature has been decreasing for more than 20 years. The maximum duration of the negative trend is registered in January and February (27 years). Observed by seasons, the longest period of hiatus is in winter (25 years). At seven months, the hiatus is present at the meteorological station Sombor, while at 5 it is longer than 20 years. Data from the beginning of measurement show a negative trend in February from 1957 (56 years), and for December from the first year of measurement – 1949 (64 years).

The matching of statistically significant values of the impact of teleconnection on air and water temperatures is observed for winter for the NAO, for spring for the AO, and for summer and autumn for the AMO. The trend of the NAO index in winter season during the hiatus, which is for air and water temperatures of the same length (25 years), is negative (and statistically significant). In the report of the IPCC [1], where the NAO response is being considered to anthropogenic forcing, presented models do not indicate a statistically significant negative trend of the NAO. There is no doubt that natural factors are dominant in the decrease of winter air temperatures in Sombor and the Danube waters in the last 25 years (1988-2013). The negative trend of the temperature changes by a sign does not fit in the hypothesis of the dominance of the GHG impact.

It is obvious that the physical causes for global warming pause are not known and its mechanism remains controversial [50]. There is also the controversy of anthropogenically-in-

duced climatic warming [51]. Sillmann, *et al*. [9] consider the regional inconsistency between models and observations a possible key to understanding the recent hiatus. In the period 1999-2012, the hiatus in surface warming was evident mainly in the central and eastern Pacific, as well as the anomalies in atmospheric circulation [52]. Yao, *et al*. [53] consider the global warming hiatus a natural product of interactions of a secular warming trend and a multi-decadal oscillation. The fact is that the occurrence of a strong El Nino 1997/1998 affected the global temperature and that it is important for the beginning of the hiatus. On the other hand, the ENSO phenomenon cannot be with certainty brought into connection with the anthropogenic forcing. Ray and Giese [54], conclude that *there is no evidence that there are changes in the strength, frequency, duration, location or direction of propagation of El Nino and La Nina anomalies caused by global warming during the period from 1871 to 2008*.

Volcanic eruptions contribute to slowing global warming, but they are not the sole or primary cause [55].

Lean and Rind [56] noted that decreasing solar irradiance countered much of the anthropogenic warming in the period 2002-2008. Since, according to forecasts of NASA, the following two solar cycles are going to be below average by intensity, an eventual temperature drop of 1 °C-1.5 °C could be expected and accumulation of much water in the form of ice on the continents [57].

It is evident that the hiatus contributes to scepticism regarding the true nature of global warming, and it is a challenge for climate models [58].

Acknowledgments

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