IMPACT OF GLOBAL WARMING ON AVERAGE ANNUAL AIR TEMPERATURE IN VARAŽDIN

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Abstract: *Climate change implies a statistically significant change in the long-term mean state or characteristics of the variability of climate elements. It can be caused by natural and/or anthropogenic factors. Recent global warming is often cited as an example of human-induced climate change. Global warming refers to the increasing trend of the average global surface temperature of the Earth, defined as the global average of the mean annual surface temperature of the ocean, usually to a depth of 30-100 cm, and the mean annual surface temperature of the air above the land at a height of 1-2 m above the ground. In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the International Panel on Climate Change (IPCC), which assesses the state of the climate and the risk of climate change caused by human activities.To project climate change, it is necessary to determine the future emissions of greenhouse gases in the atmosphere. According to the IPCC, with appropriate scenarios of greenhouse gas emissions, an increase in the average global surface temperature of 1.5 °C to 4 °C is predicted by the end of the 21st century. The purpose of this paper is to show the relationship between the trend and variability of the global average of the mean annual surface temperature on Earth and the trend of the mean annual air surface temperature in Varaždin for the period 1949-2021. The results show significant correlations among them because Varaždin is located in an big area of surface air temperature anomalies which has a significant contribution to a global average anomalies in several last decades.*
Keywords: *climate change, global warming, long-term projections of mean global surface temperature, air temperature in Varaždin*

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1. INTRODUCTION

Climate of Earth atmosphere stands out as one of the most important components of the environment. The human population has to adapt to the climate and protect itself from possible harmful climatic influences. Global climate changes are associated with changes in the Earth's energy balance. Local climate changes refer to geophysical changes in a smaller area (e.g. deforestation) (Branković 2014). **Figure 1** shows the 10 globally warmest years from the beginning of continuous meteorological measurements until 2021.

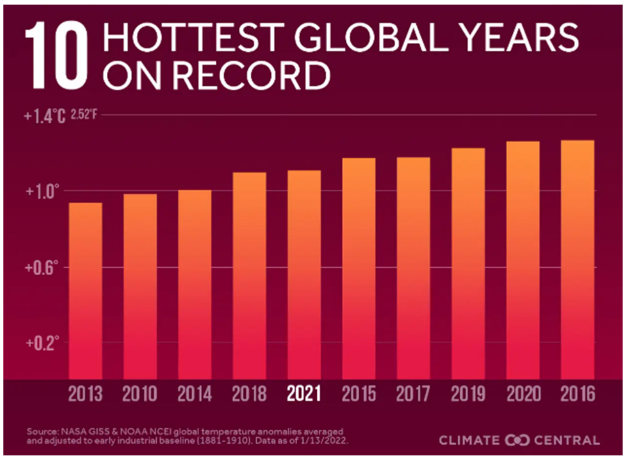

Figure 1. *The 10 warmest years globally from the beginning of systematic meteorological measurements until 2021 (Climate Central 2022)*

According to temperature analyzes of the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), the year 2021 was the 6th warmest year on Earth since the beginning of systematic meteorological measurements. According to the analysis of the non-profit organization Climate Central, the year 2021 was 1.1 °C warmer than the multi-year average for the period from 1881 to 1910 (Climate Central 2022).

NASA declared 2020 the warmest year so far since the beginning of systematic meteorological measurements, while NOAA declared it the second warmest year. According to the analysis of the organization Climate Central, the year 2020 was 1.25 °C warmer than the multi-year average for the period from 1881 to 1910 (Climate Central 2021).

Scientists, with very high confidetality, are sure that the global temperature will continue to rise in the coming decades, mainly due to greenhouse gases created by human activity. In its latest 6th report, the IPCC, in the preparation of which thousands of scientists around the world were involved, predicts the growth of global temperatures from 1.5 °C to 4 °C by the end of the 21st century (**Figure 2**) based on the results of the IPCC special report on limiting global warming to 1.5 °C (IPCC 2021). The five illustrative scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in watts per square metre, or W/m^2) resulting from the scenario in the year 2100. **Figure 2** shows five scenarios of the development of greenhouse gas emissions: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5. Also, the change in the global surface air temperature from 2081 to 2100 is presented in reference to the average for the period from 1850 to 1900. Within a particular scenario, the first column shows the total global surface warming [°C], in the second column warming caused by CO_2 emissions, in the third column warming caused by emissions of other gases except CO_2 and in the fourth column net cooling from land-use aerosols. A vertical line on each column shows the possible warming range. The influence of CO_2 emissions is dominant compared to non-CO_2 emissions. Darker shaded bars indicate warming so far. A smaller contribution to mitigating global warming comes from aerosols and land use (IPCC 2021). The net annual costs due to the adverse effects of weather and climate extremes will increase over time as the global temperature increases (IPCC 2007).

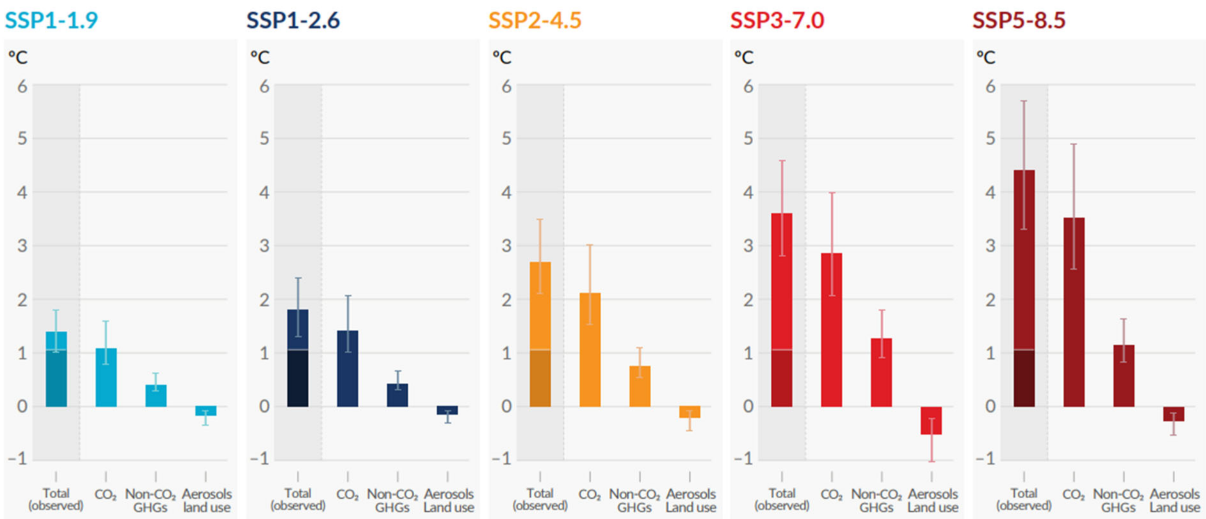

__Figure 2.__ Greenhouse gas emission scenarios until the end of the 21st century and changes in global surface temperature for the period 2081 - 2100 compared to the period 1850 - 1900 (IPCC 2021)

Figure 3a, in the upper part of the figure, shows a comparison of the measured and climate model-simulated changes in the mean annual air temperature at global warming of 1 °C. Regional warming, which corresponds to global warming of 1 °C, is visibly more pronounced on the continents than over the oceans, it is more pronounced in the northern hemisphere than in the southern, and especially in the Arctic area. It can be concluded that the measured and simulated changes in mean annual air temperature are consistent. **Figure 3b**, in the lower part of the figure, shows the simulated change in the mean annual surface air temperature in reference to the period from 1850 to 1900 at global warming of 1.5 °C, 2 °C and 4 °C. It should be noted the consistency in the geographical distribution of the intensity of change in mean annual temperature for all three scenarios of global warming (IPCC 2021).

This paper presents and analyzes the change in mean annual air temperature for Varaždin meteorological station for the period from 1949 to 2021. Average daily air temperature data for the city of Varaždin were taken from the Croatian Meteorological and Hydrological Service (DHMZ). The annual average, five-year moving average and a multi-year average of the mean annual temperature were calculated, and a graph was created based on these data. To confirm the stochastic connection between the mean annual global surface temperature and the mean annual air temperature for the city of Varaždin, it was necessary to show the change in the mean annual surface temperature for the period from 1949 to 2021 for the global level. At the end, the stochastic relationship of the respective global and temperature for the weather station Varaždin was analyzed and graphically presented.

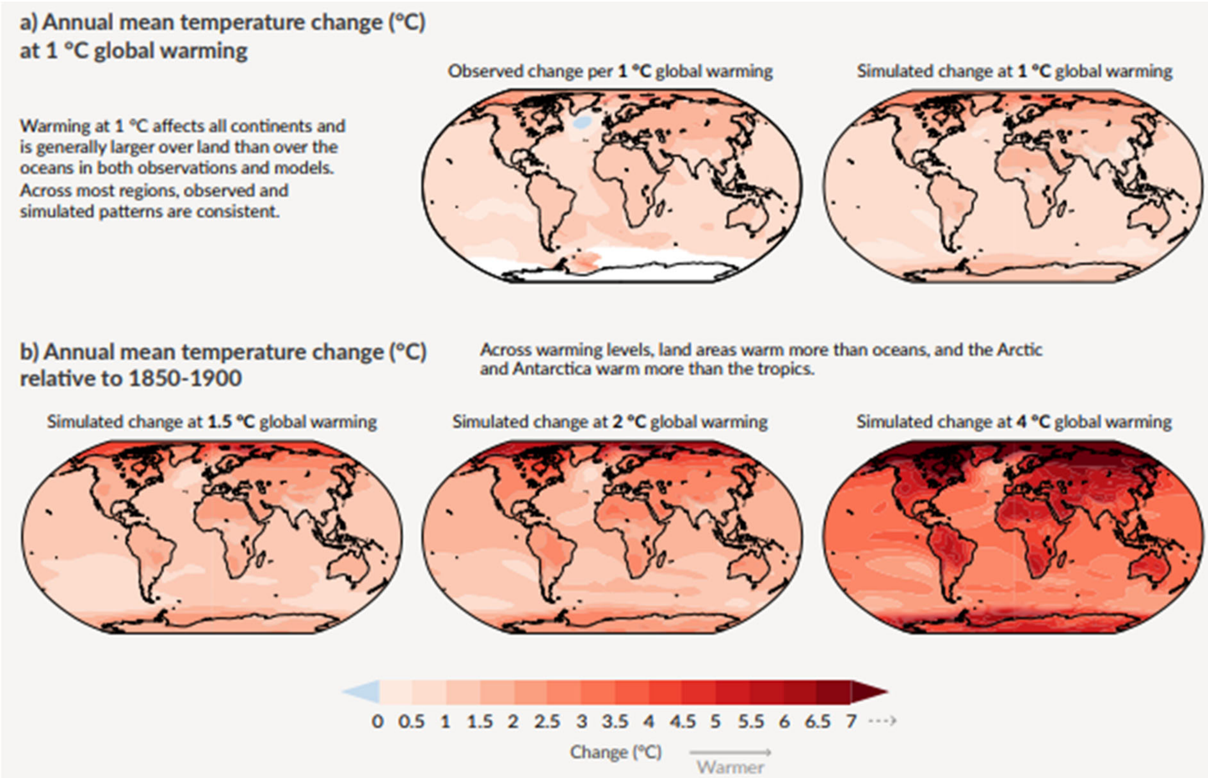

***Figure 3.** a) comparison of the geographical distribution of the observed and climate model-simulated change in mean annual temperature corresponding to global warming of 1 °C; b) distribution of the simulated change in mean annual temperature at global warming of 1.5 °C, 2 °C and 4 °C (IPCC 2021)*

2. MATERIALS AND METHODS

In Varaždin, continuous measurement of air temperature began in 1949. **Equation 1** is used to calculate the average daily air temperature:

$$t_{average} = \frac{t_7 + t_{14} + 2t_{21}}{4} \qquad (1)$$

At which:
$t_{average}$ - mean daily temperature
t_7 - temperature value measured at 7 a.m.
t_{14} - temperature value measured at 2 p.m.
t_{21} -temperature value measured at 9 p.m., local time (DHMZ 2022).

t_{21} is multiplied by 2 to be emphasised t_{21} as night term as there are 2 daily terms t_7 and t_{14}. The mean annual temperature is obtained as the sum of the mean daily temperatures divided by the number of days in the year.

With the help of data taken from DHMZ and (NASA Global Climate Change 2022), the annual temperature average and five-year moving average can be calculated for Varaždin and at the global level for the period from 1949 to 2021. The annual average represents the mean value of all mean daily temperatures in the year. The sum of average daily temperatures in a year is divided by the number of days in that year and the annual average is obtained. The five-year moving average is calculated to get an overall idea of quasi-periodic so-called interdecadal temperature fluctuations in addition to trend. In statistics, moving average refers to a calculation used to analyze data by creating a series of averages of different subsets of the entire data set (Investopedia 2022).

Equation 2 is used for calculating the simple moving average:

$$SMA = \frac{A_1 + A_2 + \cdots + A_n}{n} \qquad (2)$$

At which:
A_k - average in a certain time period k, for k =1, ..., n
n - number of time periods (Investopedia 2022).

The multi-year average refers to the 30-year reference period from 1951 to 1980 used by NASA. The multi-year average of the mean annual air temperature for the period from 1951 to 1980 for Varaždin is 9,866 °C, and at the global level it is 13,889 °C (NASA Earth Observatory 2022). The annual average surface temperature at the global level can be calculated by adding 13,889 °C to the temperature anomaly, considering the period from 1951 to 1980. In this paper, time series were formed, trends and stochastic connection between time series were analyzed at the global (average annual surface temperature) and local level (average annual air temperature for the city of Varaždin).

3. RESULTS AND DISCUSSION

3.1. Analysis of the relationship between local and global temperature trends

Figure 4 shows annual averages, five-year moving averages and multi-year averages (1951-1980) of the mean annual air temperature for Varaždin. The annual average of the mean air temperature is shown by the blue line, the five-year moving average of the mean annual air temperature by the orange line, and the multi-year average (1951-1980) by the gray line.

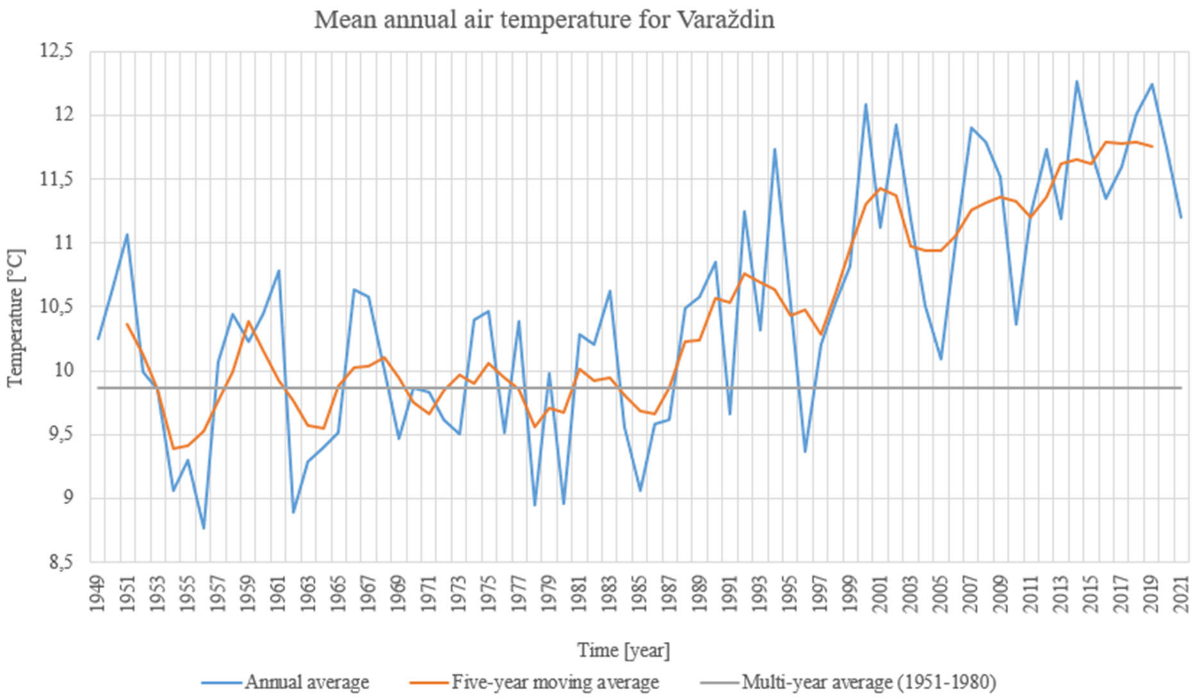

Figure 4. *Graphic display of time series of annual average (1949-2021), five-year moving average and multi-year average (1951-1980) of air temperature for Varaždin*

From the graphic representation, it can be concluded that the annual average or mean air temperature for Varaždin is gradually increasing and since 1997 it has been higher than the multi-year average for the period from 1951 to 1980. In the five-year moving average, a similar increase has been observed since 1987. The minimum annual average air temperature for Varaždin is 8.76 °C for the year 1956 when it was one of the strongest winters in Croatia since measurements have been available. The maximum annual average air temperature for Varaždin is 12.27 °C in 2014.

Figure 5 shows annual averages, five-year moving averages and multi-year averages (1951-1980) of mean global surface temperature. It can be concluded that since 1977, the annual average of the mean global surface temperature has not fallen below the reference average, although accompanied by certain interannual changes.

Figure 6 shows a scatter diagram between the mean annual global surface temperature and the mean annual air temperature for Varaždin. Each data pair is shown with a blue dot, and the points are assigned a regression line, to which belongs the corresponding regression equation and the coefficient of determination that represents the square of the correlation coefficient. The coefficient of determination shows how much percent of the variance of one variable can be described by another variable. In this case, the R-squared value is 0.4958. According to the coefficient of determination, it is determined whether there is a significant stochastic (statistical) relationship between the corresponding global surface temperature and the air temperature for Varaždin: including the increase in air temperature for Varaždin from 1949 to 2021, which follows the global warming clearly expressed since the beginning of the 1980s.

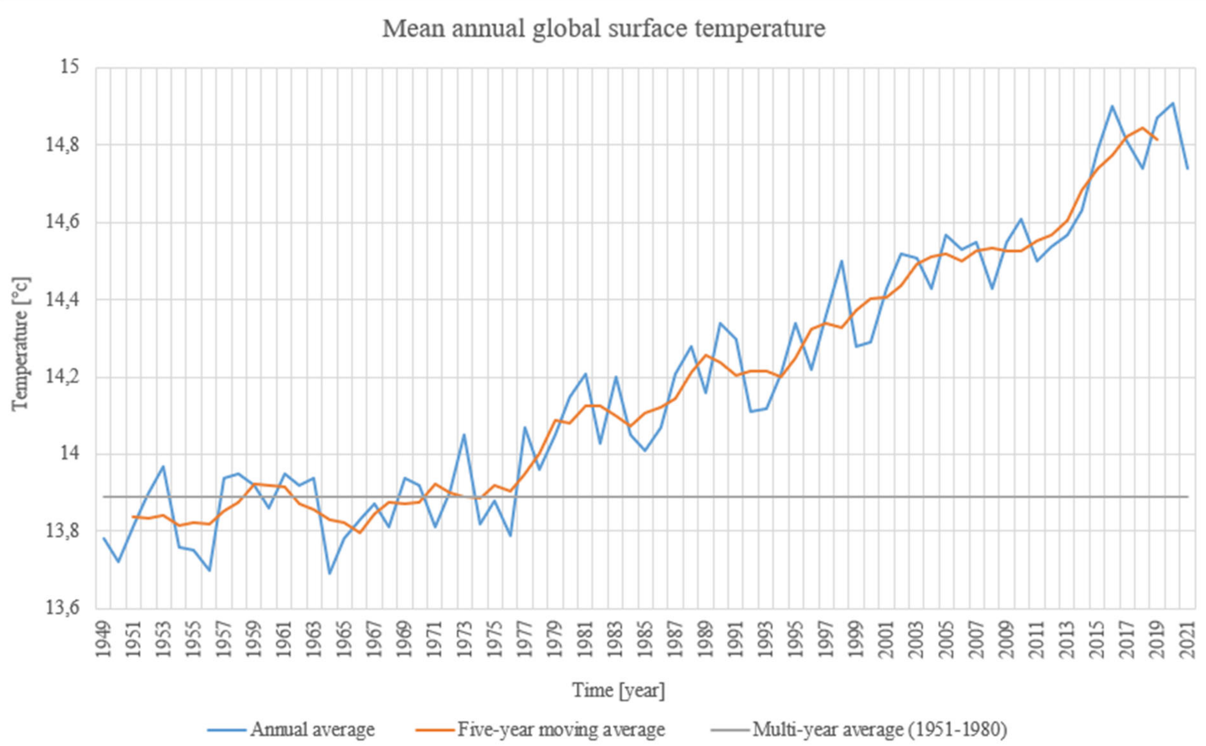

Figure 5. *A presentation of annual average, five-year moving average and multi-year average (1951-1980) of mean annual global surface temperature for the period 1949-2021*

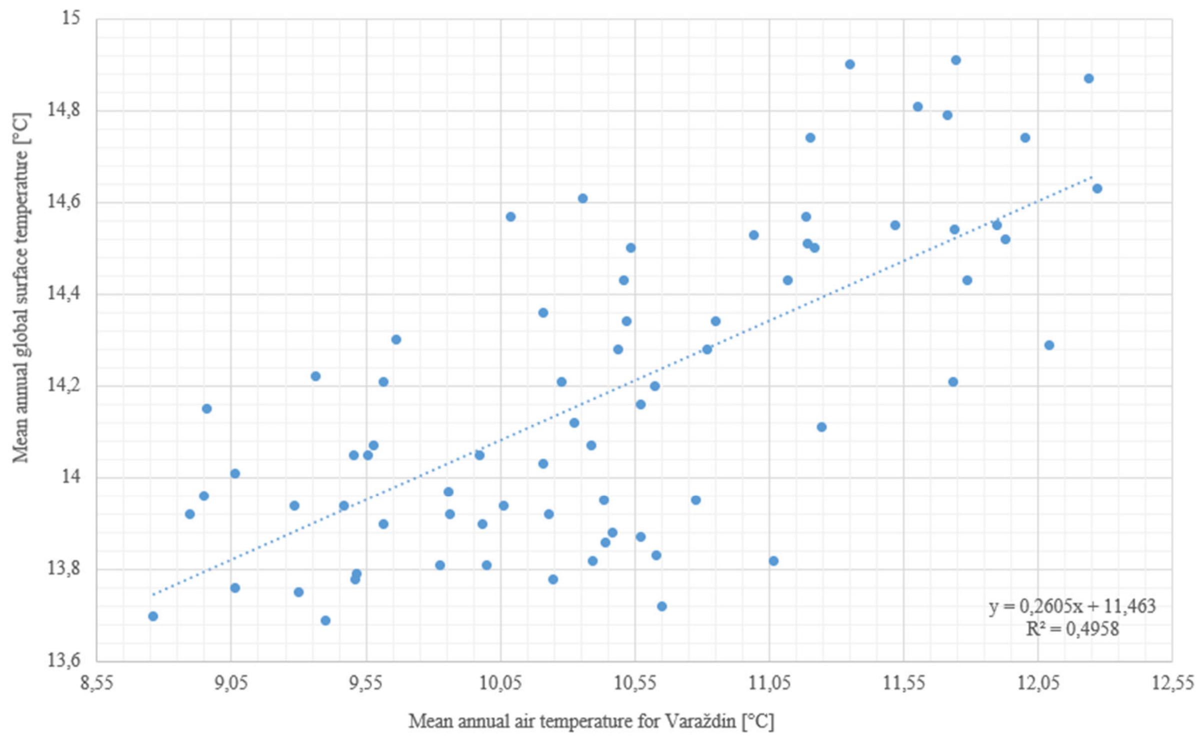

Figure 6. *Scatter diagram between mean annual global surface temperature and mean annual air temperature for Varaždin*

To get an overall idea of the trend in the data set, a graphic representation of the relationship between global and mean daily temperature for Varaždin was created using five-year moving averages (**Figure 7**). The five-year moving average of the mean annual temperature for Varaždin is shown on the abscissa, and the five-year moving average of the mean annual temperature on the global level is shown on the ordinate. In this case, the R-squared value is 0.8362. From the above, it can be concluded that the stochastic relationship between the rise of temperature at the global level and in Varaždin, especially after the 1990s of the last century until 2021. Such a result is a consequence of the spatial distribution of the increase in mean annual surface temperature anomalies up to now in reference to the pre-industrial period (1859-1900) shown in **Figure 3a**. A similar relationship is expected until the end of the 21st century (1981-2100), for which period the scenario of the spatial distribution of changes in mean annual temperature is shown in **Figure 3b**.

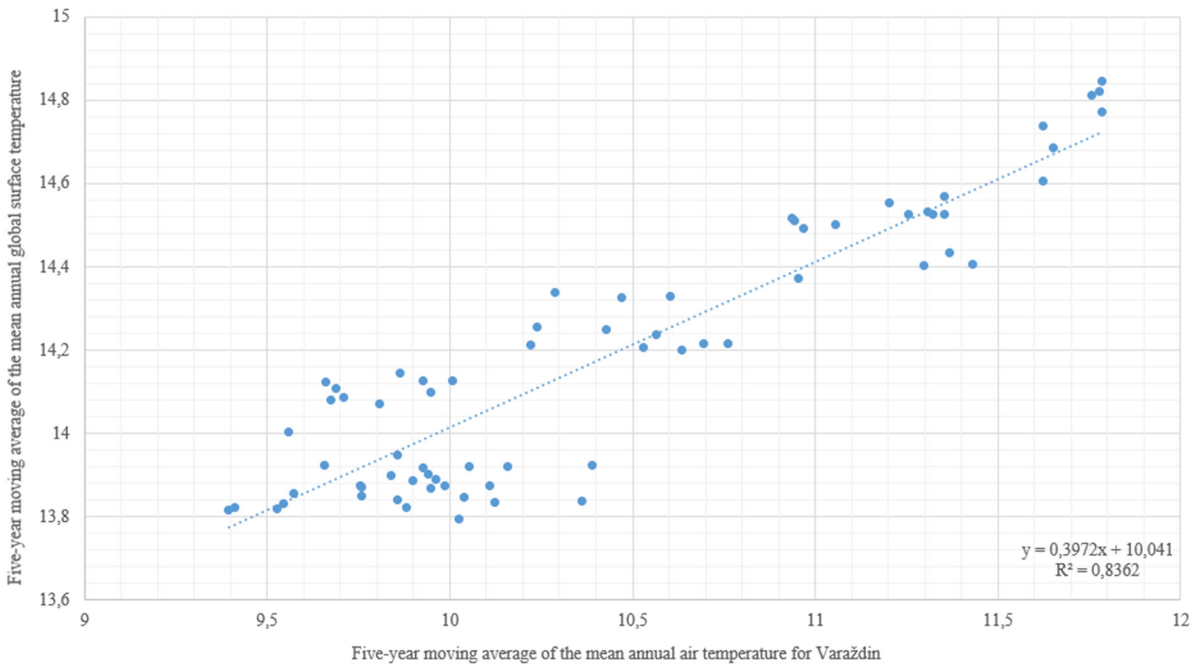

Figure 7. *Scatter diagram between the five-year moving average of the mean annual global surface temperature nad the moving average of the mean annual air temperature for Varaždin*

The NASA results published on its website are very illustrative (NASA Scientific Visualization Studio 2021**).** Five-year surface temperature anomalies compared to the 1951-1980 average were published on that portal. Until the beginning of the 1980s, positive and negative anomalies were evenly distributed around the globe (**Figure 8a**). After that, positive anomalies occupy more and more space on Earth (**Figure 8b**). The significant correlation between global and temperature for Varaždin is a consequence of Varaždin's position in relation to the vast European-Asian area with the most pronounced global warming in the entire globe. It is interesting that, according to the results of climate models, the approximate configuration of global warming anomalies is expected until the 21st century almost independently of the greenhouse gas emission scenario, taking into account the fact that anomalies are larger for scenarios with higher greenhouse gas emissions.

3.2. Time series analysis

A time series is a chronologically arranged set of values of a variable that shows a certain phenomenon in time (Šošić 2006). In our case, it is about two variables: the average annual air temperature for Varaždin and the average global surface air temperature, respectively, in a time interval of 73 consecutive years (from 1949 to 2021). Graphic representation of these time series can be found in **Figures 4** and **5** (the corresponding graph lines are marked in blue). Since the increase in the average annual air temperature in Varaždin and the average global surface air temperature is visible from the graphic display, linear trend models will be constructed for both variables in order to describe the behavior of the observed temperature over time and so that temperature in the future can be extrapolate using them for years.

The linear model was incorporated into the time series of mean daily temperature with the purpose of determining the presence of a trend of increasing air temperature in Varaždin and global surface air temperature.

The linear trend model is essentially the same as the simple linear regression model in which the independent variable is time t (Šošić 2006). The direction coefficient in that model represents the average linear temperature change in a year, and the constant term is treated as the value of the linear trend for the year preceding the first term of the time series.The representativeness indicator of the trend model is the coefficient of determination R^2.

The mentioned linear trend was modeled in Excel, and the function of the linear trend of the mean annual temperature for Varaždin was obtained using **Equation 3** (**Figure 9**):

$$T = 0.028517 \cdot t + 9,397761 \qquad (3)$$

where t represents the time in years (t=1 represents the first year for which measurements were made, 1949), and T average annual air temperature for Varaždin.

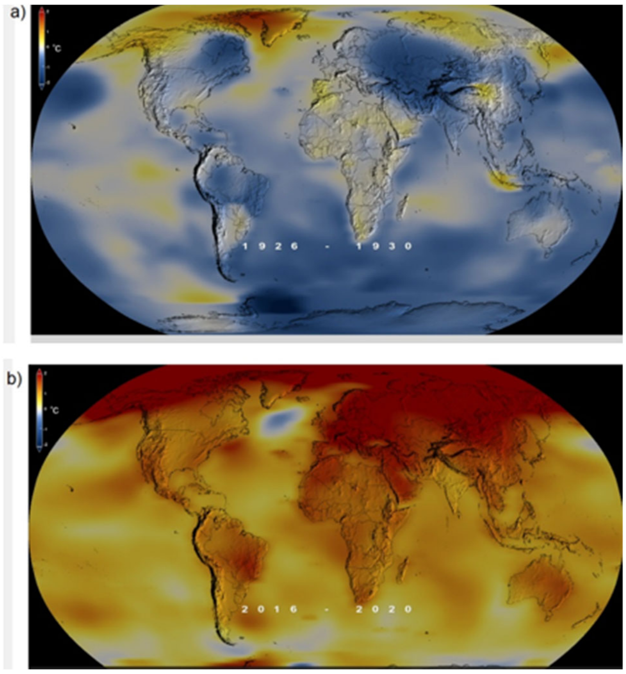

Figure 8. *Change in the distribution of the five-year mean of surface temperature anomalies in relation to the reference period 1951-1980 for the period: a) 1926-1930 and b) 2016-2020 (NASA Scientific Visualization Studio 2021)*

Note that the constant term is 9.397761, and the direction coefficient is 0.028517. This means that it was estimated that in 1948 the average annual air temperature in Varaždin would be 9.397761 °C, and the mean annual temperature for Varaždin increases on average linearly by 0.028517 per year. Using this linear trend model, we can estimate future trends in the average annual air temperature for Varaždin. For example, we can predict that the average annual air temperature in Varaždin in 2028 (t=80) would be (**Equation 4**):

$$T = 0{,}028517 \cdot 80 + 9{,}397761 = 11{,}679121\ °\text{C}. \qquad (4)$$

The coefficient of determination of this linear trend amounts to R^2=0.439043, which we interpret as a poor representative trend.

Equation 5 shows the linear trend function of the mean annual global surface air temperature (**Figure 10**):

$$T = 0{,}014938 \cdot t + 13{,}63277 \qquad (5)$$

where t= time in years, and T is the mean annual global surface air temperature.

In this model, the constant term is 13.63277 and it represents the estimated value of the mean annual global temperature for the year 1948, while the direction coefficient is equal to 0.014938 and we interpret it as a linear increase of the mean annual global temperature in a year. Using this model, we can forecast values for the following years, for example, the forecast value of the mean annual global temperature in 2028 (t=80) is (**Equation 6**):

$$T = 0{,}014938 \cdot 80 + 13{,}63277 = 14{,}82781\ °\text{C}. \qquad (6)$$

The coefficient of determination of this linear trend amounts to R^2=0.880278 which leads us to the conclusion that it is a representative linear trend.

3.2. Testing hypotheses about the significance of the regression variable on linear trend models

As we mentioned earlier, the linear trend model is a linear regression model. Now we will test the hypotheses about the significance of the regression variable (t) in the model:

- H_0: the direction coefficient is equal to 0 (that is, the variable t is redundant in the model)
- H_1:the direction coefficient is different from 0.

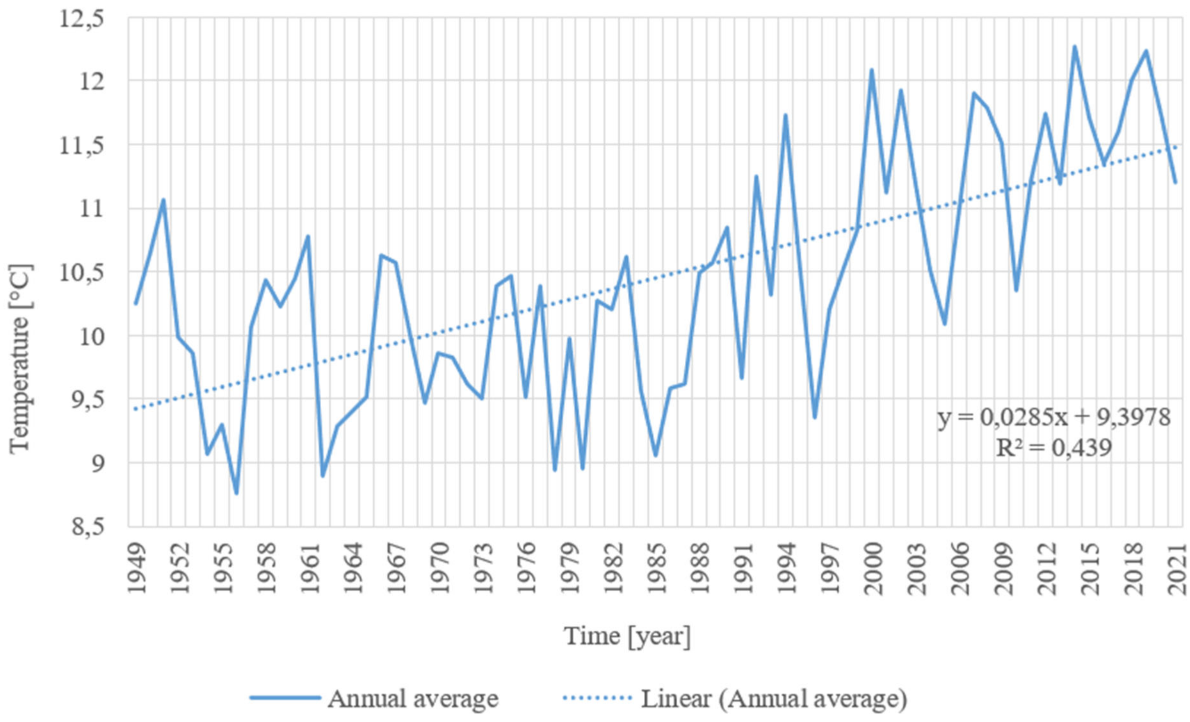

Figure 9. *The linear trend of mean annual air temperature for Varaždin*

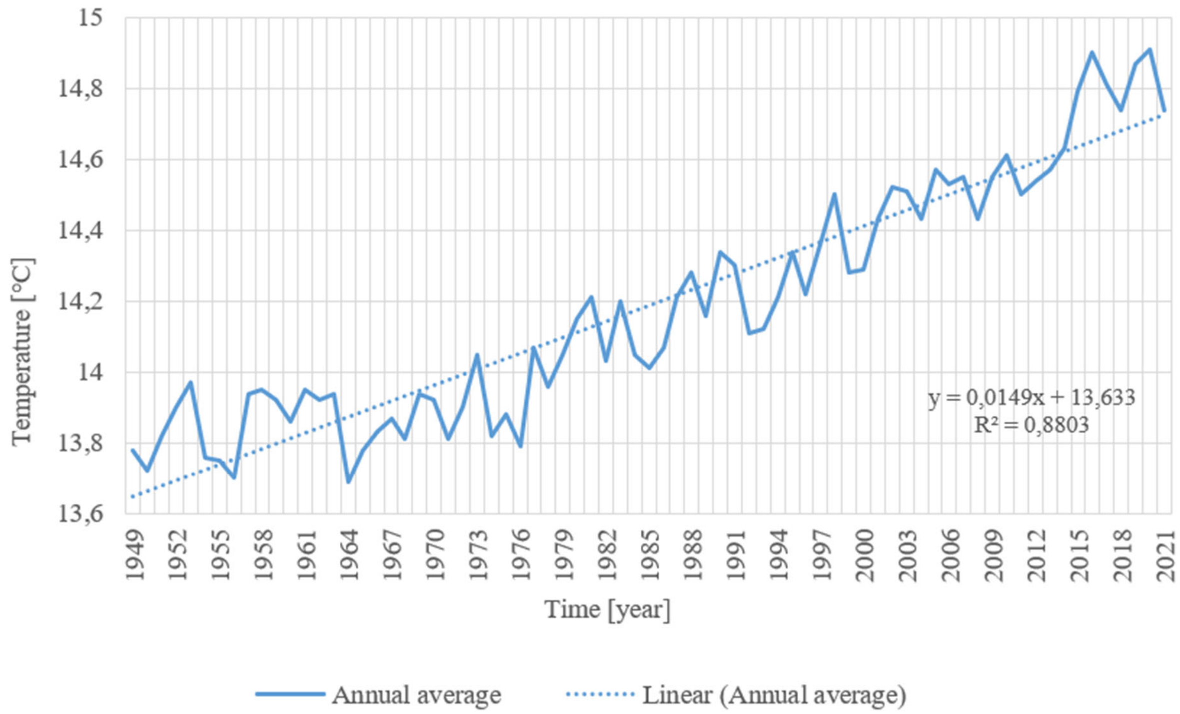

Figure 10. *The linear trend of mean annual global air temperature*

The null hypothesis (H_0) can be interpreted in such a way that the air temperature (for the city of Varaždin or globally) does not depend on time, that is, it does not change with the years. This test is based on a test statistic that has an F-distribution with (1, n-2) degrees of freedom (Pauše 1993) and whose value is obtained when calculating the regression linear model in Excel. For the level of significance $\alpha=0.05$ from the F-distribution table (Pauše 1993) for (1.71) degrees of freedom, we read the threshold value 252.2.

In the first case, when the dependent variable is the average annual air temperature for the city of Varaždin, the value of the test statistic is 55.6, which is less than the threshold value, so in this case, we cannot reject the null hypothesis. In the second case, when the observed dependent variable is the mean annual global surface air temperature, the value of the test statistic is 522, which is higher than the threshold value, so in this case, we can reject the null hypothesis, that is, we accept the obtained linear trend model.

Let's note that in the case of the first model, where the coefficient of determination is much lower than 1, and thus the model itself is poorly representative, testing the hypothesis about the direction coefficient of that linear model resulted in the conclusion that such a model is not accepted. On the other hand, in the second model where the coefficient of determination is much higher (and therefore the model is also representative), testing the hypothesis about the direction coefficient of that model resulted in the conclusion of acceptance of such a model.

3. CONCLUSION

It is often a question among the public how pronounced global warming has been in recent decades compared to the local one. This paper aims to show the stochastic relationship between the mean global annual temperature and the mean annual air temperature for Varaždin from 1949 to 2021. The results show that there is a significant relationship between the mentioned temperatures because the Varaždin area belongs to the European-Asian area where global warming is the most pronounced in the world, which according to climate scenarios will continue until the end of 21st century. According to the presented results, it can also be concluded that the linear trend model is representative in the case of the average annual global surface temperature and can be used in the prediction of future values, but with due caution given that the circumstances affecting global warming are constantly changing, for example, the concentration of greenhouse gases in the atmosphere. An additional resource for global surface temperature forecasts are scenarios of climate models. In this case, the considered regression relationship between global and local temperature for Varaždin is a preferable alternative, as are the results of climate models. The next step in researching this topic could be researching the impact of global warming on the entire area of Croatia or wider.

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