National Hydrometeorological Service - Skopje

ANALYSIS AND INTERPRETATION OF CLIMATE VARIABILITY AND CLIMATE CHANGE IN THE REPUBLIC OF NORTH MACEDONIA

Skopje, May 2021

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The last decade of the 20th century and the beginning of the 21st century are climatically the warmest periods in the world. These are the most specific periods in terms of weather and climate in the Republic of North Macedonia as well. Under the influence of natural conditions as well as under the influence of human activities in the last thirty years, changes in climate take place around the world, and Southeast Europe and the Republic of North Macedonia are no exception. Climate change can be clearly detected in long-term series of climate data and it is primarily characterized by rising air temperatures, changes in precipitation patterns, as well as by higher frequency of extreme weather events and periods of extreme climatic conditions.

To show these changes, an analysis of the variability of the main climatic elements: air temperature, precipitation and snow cover was performed. The analysis used data from the period 1926-2020 measured at the meteorological stations Bitola, Prilep and Shtip (as measuring stations with the longest data series in the Republic of North Macedonia), data from the period 1951-2020 measured at the measuring points with shorter data series such as Demir Kapija, Strumica, Gevgelija, Kriva Palanka, Berovo, Ohrid and Lazaropole and the analyses were conducted annually and seasonally. A comparative analysis of the three series for a 30-year period was also made, i.e. a comparison of the periods 1971-2000, 1981-2010 and 1991-2020 with the period 1961-1990 and an analysis of the decadal values for the period 1951-2020 in comparison to the period 1961-1990.

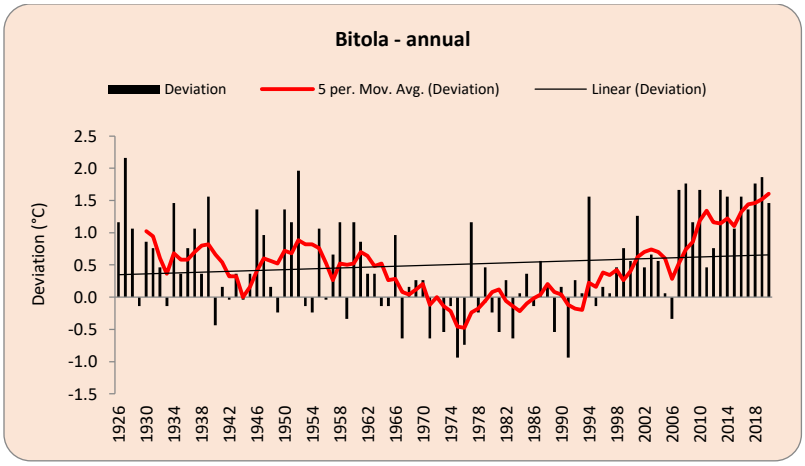
The conclusions of this research are made on the basis of climate data registered at meteorological stations covering the entire territory of the country and all characteristic climatic zones.

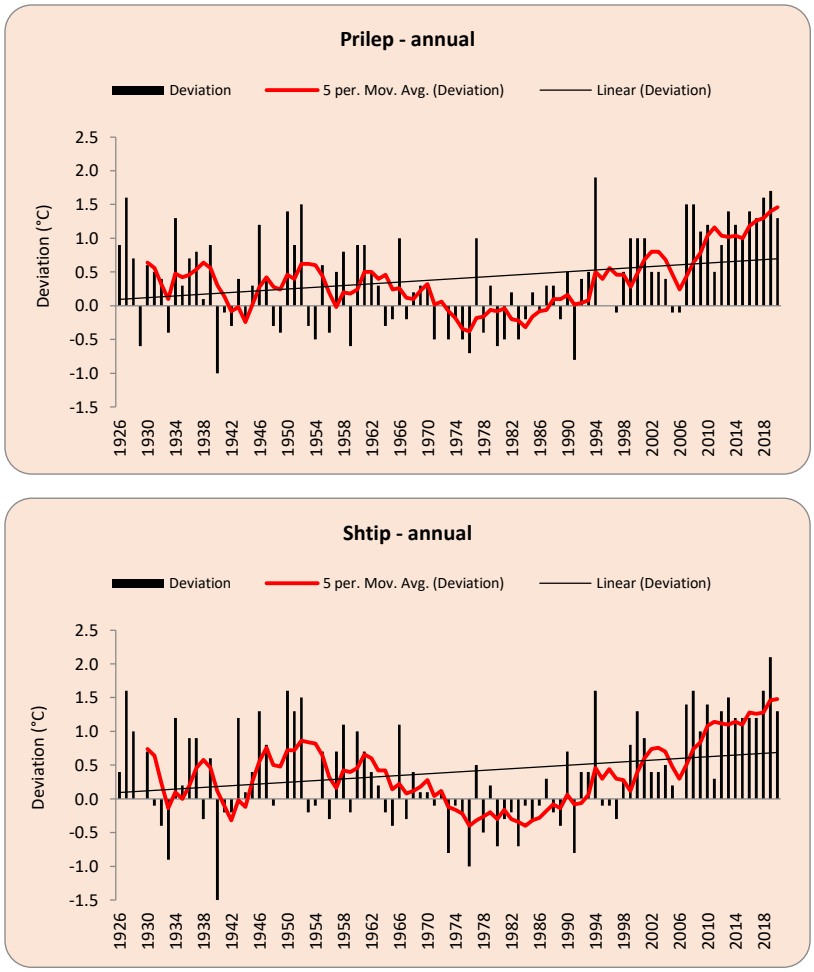
1. CLIMATE VARIABILITY OF AIR TEMPERATURE

The analysis of the multi-year change in the mean annual air temperature (Graph 1), shows that during the fifties of the 20th century, relatively higher air temperatures were measured, followed by a colder period from 1971 to 1993. In the period from 2007 to 2020, the mean annual air temperature is continuously higher than the average for the period 1961-1990. Due to the lack of measurements and data before 1926 it is impossible to calculate a relevant multi-year temperature trend and compare it with regional or global temperature trends based on measurements from the beginning of the instrumental period until today (1850-2020).

The multi-year variation of the mean annual air temperature during the ninety-five year period ranges from 10.1°C to 13.2°C for Bitola, from 10.1°C to 13.0°C for Prilep and from 11.2°C to 14.8°C for Shtip. The average annual air temperatures for the standard thirty-year climatic period (1961-1990) are 11.0°C for Bitola, 11.1°C for Prilep and 12.6°C for Shtip. The difference of the average annual air temperature for the whole period (1926-2020) in comparison to the average annual temperature for the period 1961-1990 is 0.4°C for Prilep and 0.5°C for Bitola and Shtip.

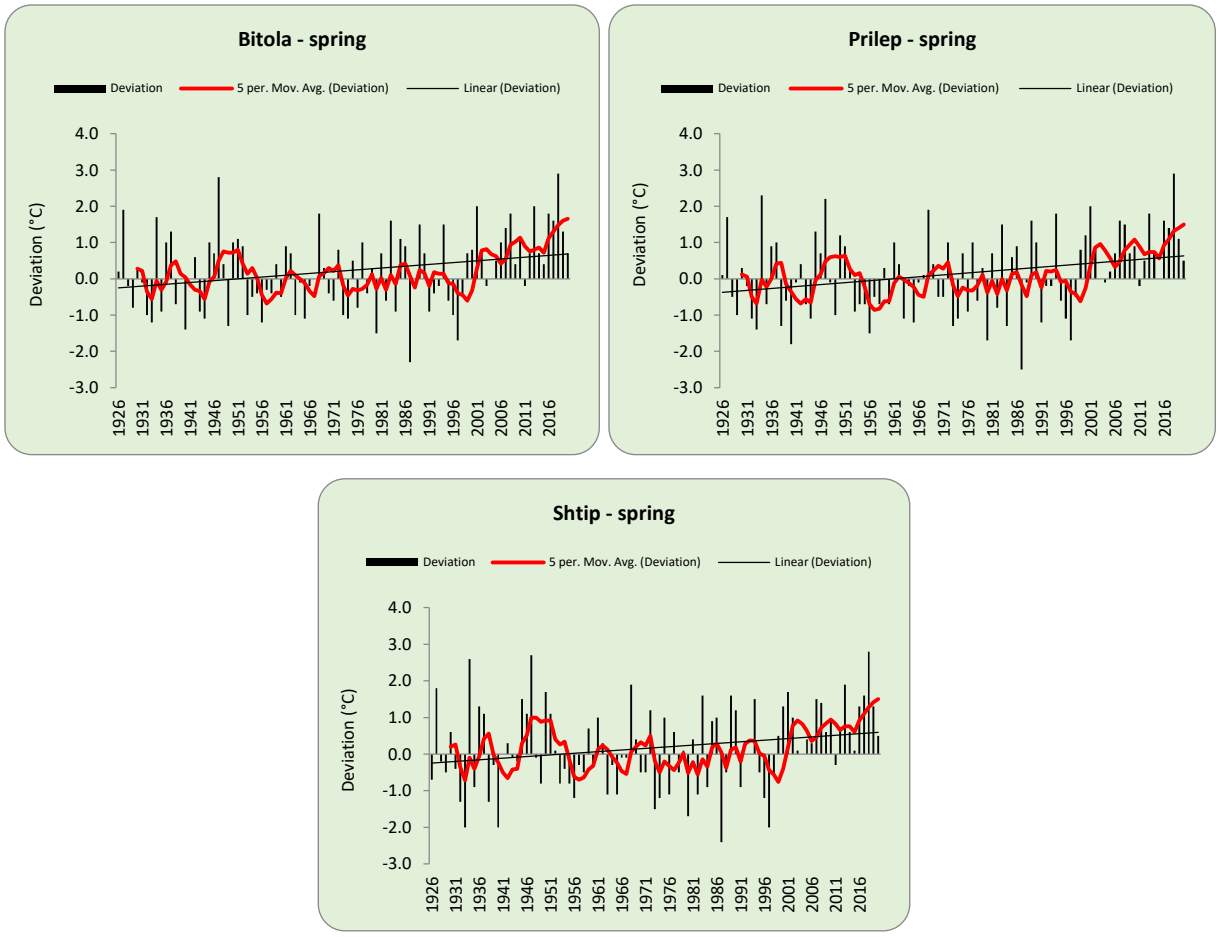
The warmest years recorded on the territory of the Republic of North Macedonia for the period 1951-2020, for which data are available for all meteorological stations, are 2019, 2018, 1994 and 1952. The last fourteen consecutive years (2007-2020), with the exception of 2011, are years in which the seven highest values of annual air temperature (period 1951-2020) have been recorded. The coldest years are observed in the colder twenty-year period, with 1991, 1983, 1980, 1976 and 1973 standing out.





Graph 1. Deviation of the annual air temperature from the average for the period 1961-1990

The spring air temperature for the period 1926-2020 ranges from 8.7°C to 13.9°C for Bitola, from 8.3°C to 13.7°C for Prilep and from 10.1°C to 15.3°C for Shtip. The difference of the average spring air temperature for the whole period in comparison to the average temperature for the period 1961-1990 is 0.1°C for Prilep and 0.2°C for Bitola and Shtip. In the last twenty years (Graph 2) there is a gradual increase in spring air temperatures. From the data on the spring air temperature (period 1951-2020) it can be concluded that the highest values were observed in 2018, 2017, 2013, 2007, 2001, 1994 and 1968, and the lowest values in 1980, 1987 and 1997.



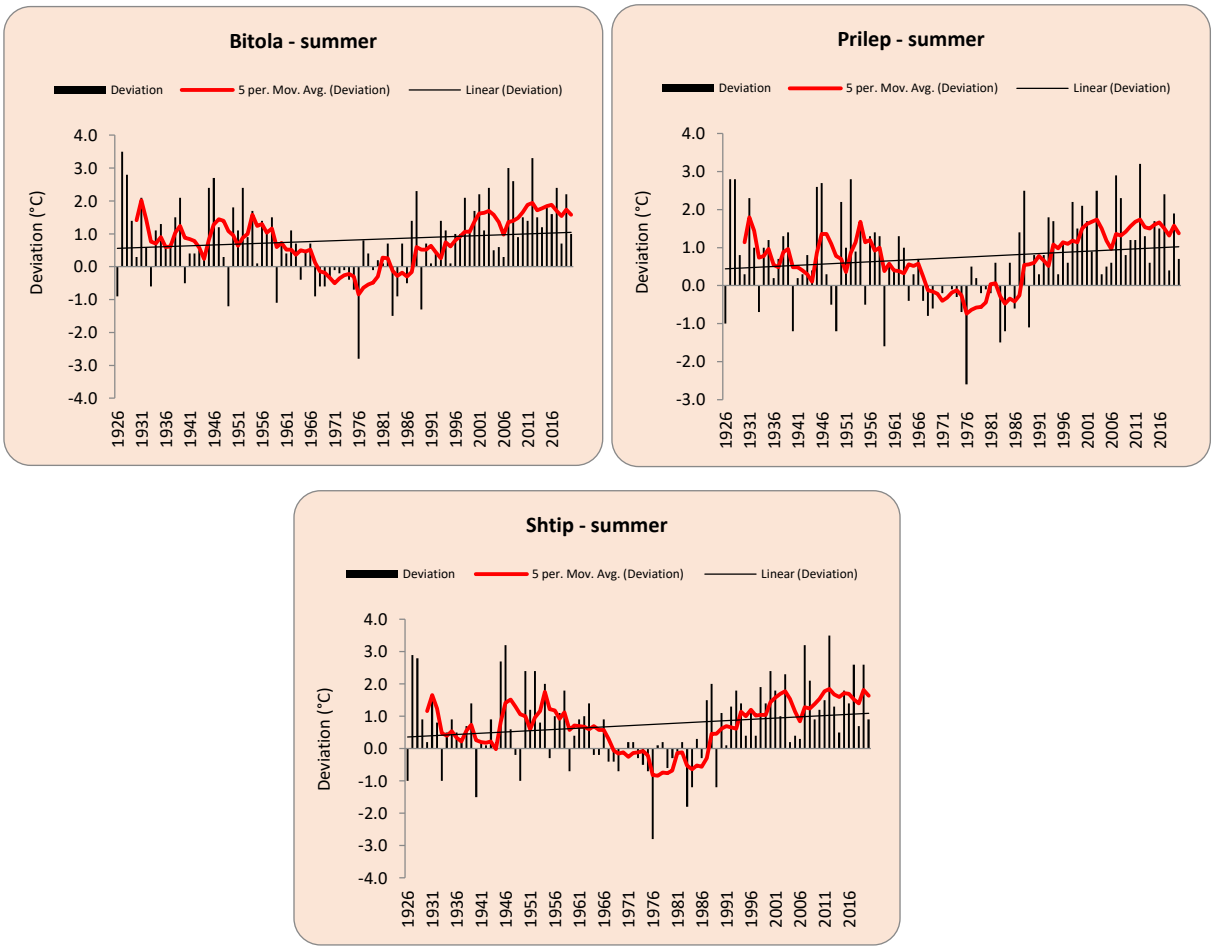
Graph 2. Deviation of the spring air temperature from the average for the period 1961-1990

Summer air temperature (period 1926-2020) ranges from 18.0°C to 24.3°C for Bitola, from 18.1°C to 23.9°C for Prilep and from 19.8°C to 26.1°C for Shtip. The average values of summer air temperatures for the period 1961-1990 are 20.7°C for Prilep, 20.8°C for Bitola and 22.5°C for Shtip.

During the summer in the last years of the 20th century and in the beginning of the 21st century (Graph 3) there are significantly higher values of air temperature, especially from 1990 to 2020. The difference between the average summer air temperature for the whole period (1926-2020) and the average temperature for the period 1961-1990 is 0.7°C for Prilep and 0.8°C for Bitola and Shtip. The hottest summers in the period 1951-2020 have been recorded in the last twenty years. The highest values of summer temperatures were recorded in 1952, 2003, 2017, 2019, and the most extreme were 2012 and 2007. The coldest summers were recorded in 1976 and 1983.

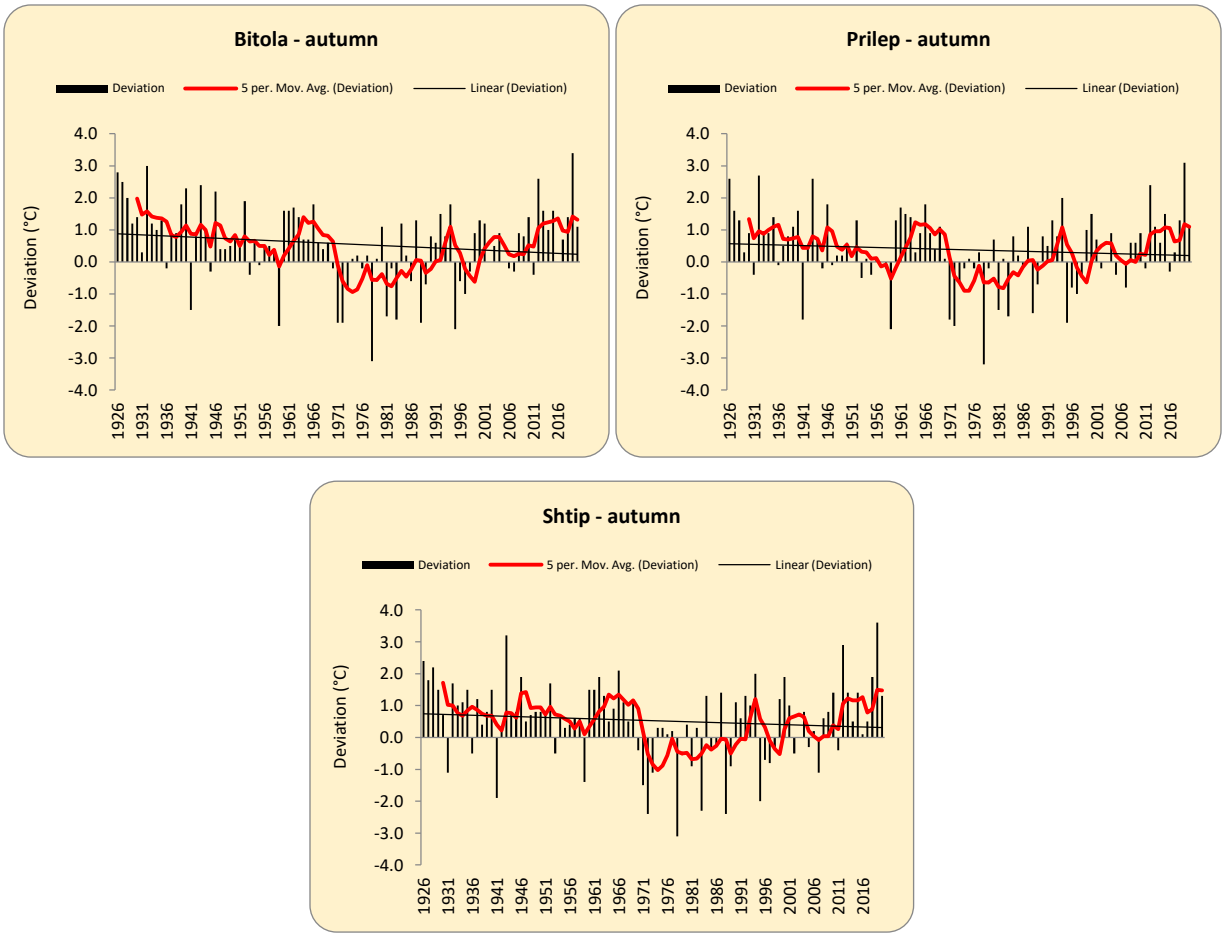
During the summer part of the year, more precisely in July, the highest values of air temperature during the year are registered. The highest maximum air temperatures in the Republic of North Macedonia at the meteorological stations Shtip, Demir Kapija, Gevgelija, Berovo, Kriva Palanka and Ohrid were measured on July 24, 2007, while at the meteorological

stations Bitola, Prilep, Strumica and Lazaropole on July 6 and 7, 1988. At the meteorological station Demir Kapija on July 24, 2007 a record 45.7°C were measured, which is the highest measured maximum air temperature since the beginning of the meteorological measurements.



Graph 3. Deviation of the summer air temperature from the average for the period 1961 -1990

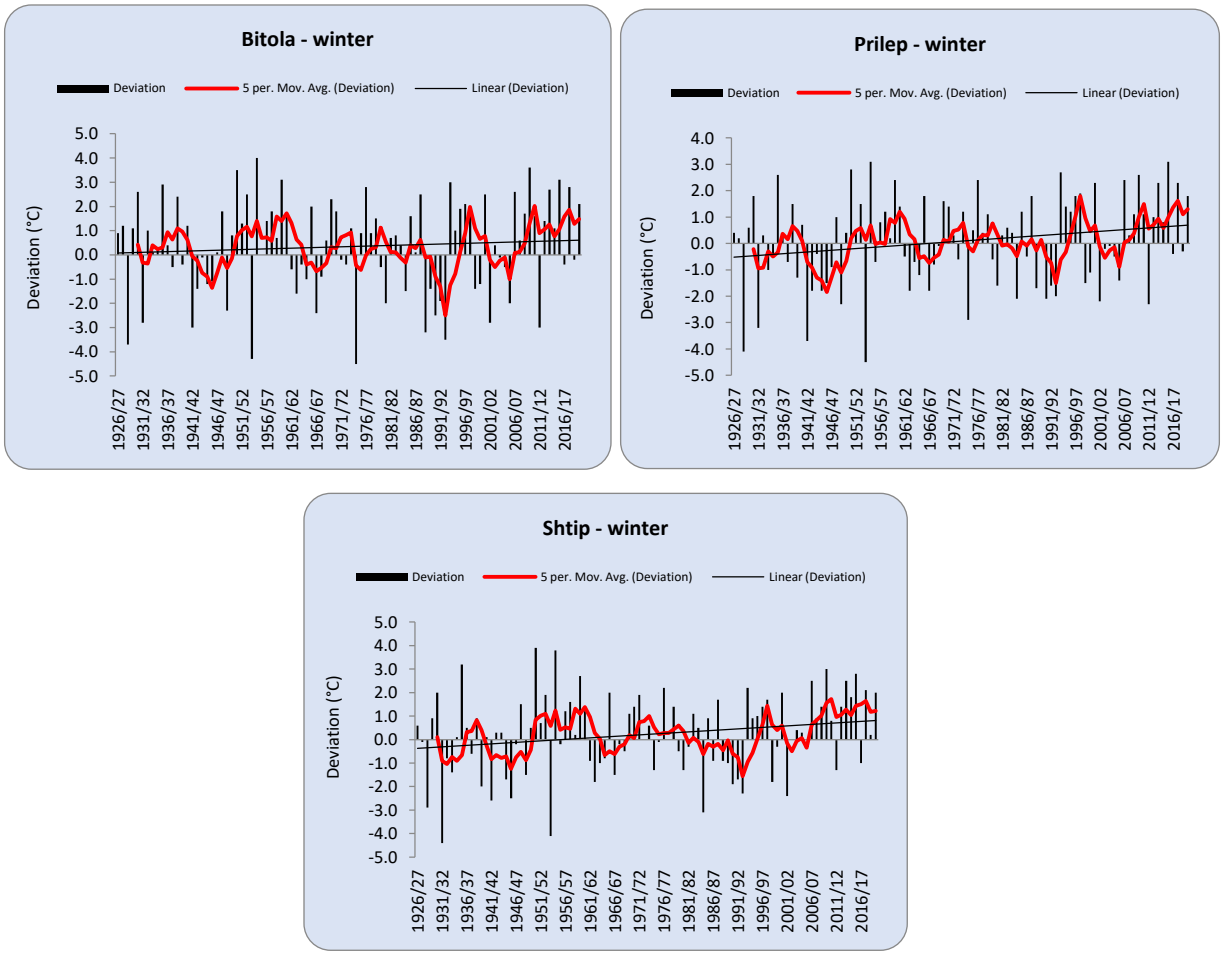
Autumn air temperature (period 1926-2020) ranges from 8.5°C to 15.0°C for Bitola, from 8.7°C to 15.0°C for Prilep and from 10.2°C to 16.9°C for Shtip. The difference of the average autumn air temperature for the whole period (1926-2020) compared to the average for the period 1961-1990 is 0.4°C for Prilep, 0.5°C for Shtip and 0.6°C for Bitola. As it can be seen (Graphs 4), the trend of decreasing autumn air temperature is evident. However, despite the declining trend, the highest values of the autumn temperature were measured in 2019 and 2012, and the lowest values in 1978.



Graph 4. Deviation of the autumn air temperature for the period 1926 -2020 from the average for 1961-1990

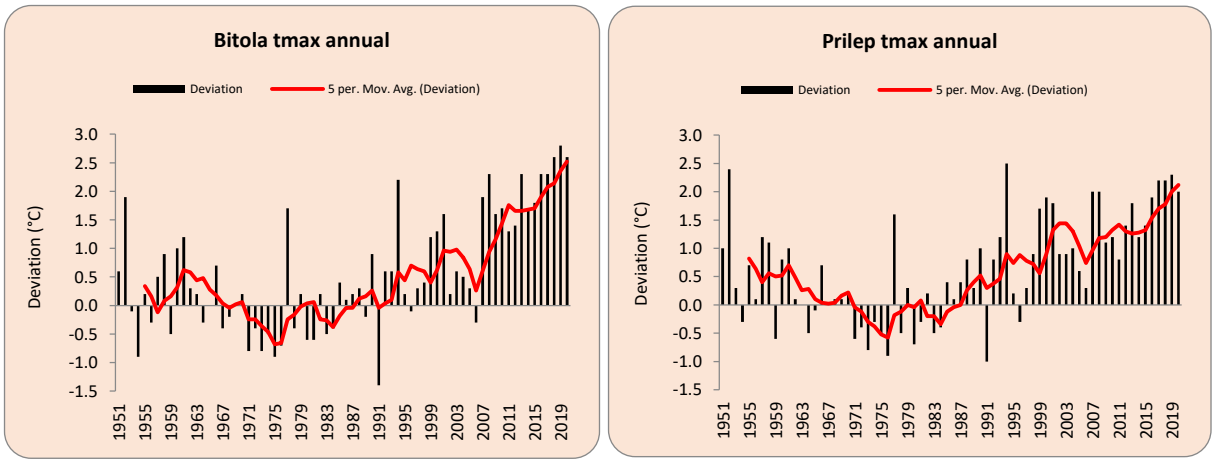
Winter air temperature (period 1926-2020) ranges from -3.8°C to 4.8°C for Bitola, from -3.3°C to 4.3°C for Prilep and from -2.1°C to 6.2°C for Shtip. The difference of the average winter air temperature for the whole period (1926-2020) compared to the average for the period 1961-1990 is 0.1°C for Prilep, 0.2°C for Shtip and 0.3°C for Bitola. There is a slight trend of increasing winter air temperature (Graph 5), while the individual values by years continuously vary in positive and negative values around the thirty-year average (1961-1990). The warmest winters (period 1951-2020) were recorded in 1954/1955, 2006/2007, 2009/2010, 2013/2014 and 2015/2016.

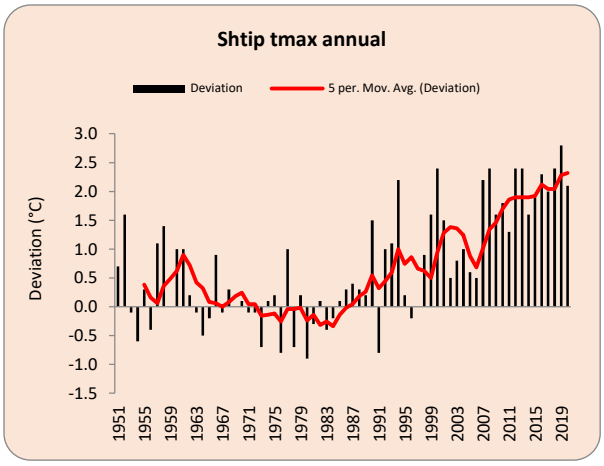
The lowest air temperatures during the year were registered in the winter months of the year. The absolute minimum air temperatures at all meteorological stations, with the exception of Lazaropole, were measured in January. The lowest value of the minimum air temperature on the territory of the Republic of North Macedonia -31.5°C was measured in Berovo on January 27, 1954.



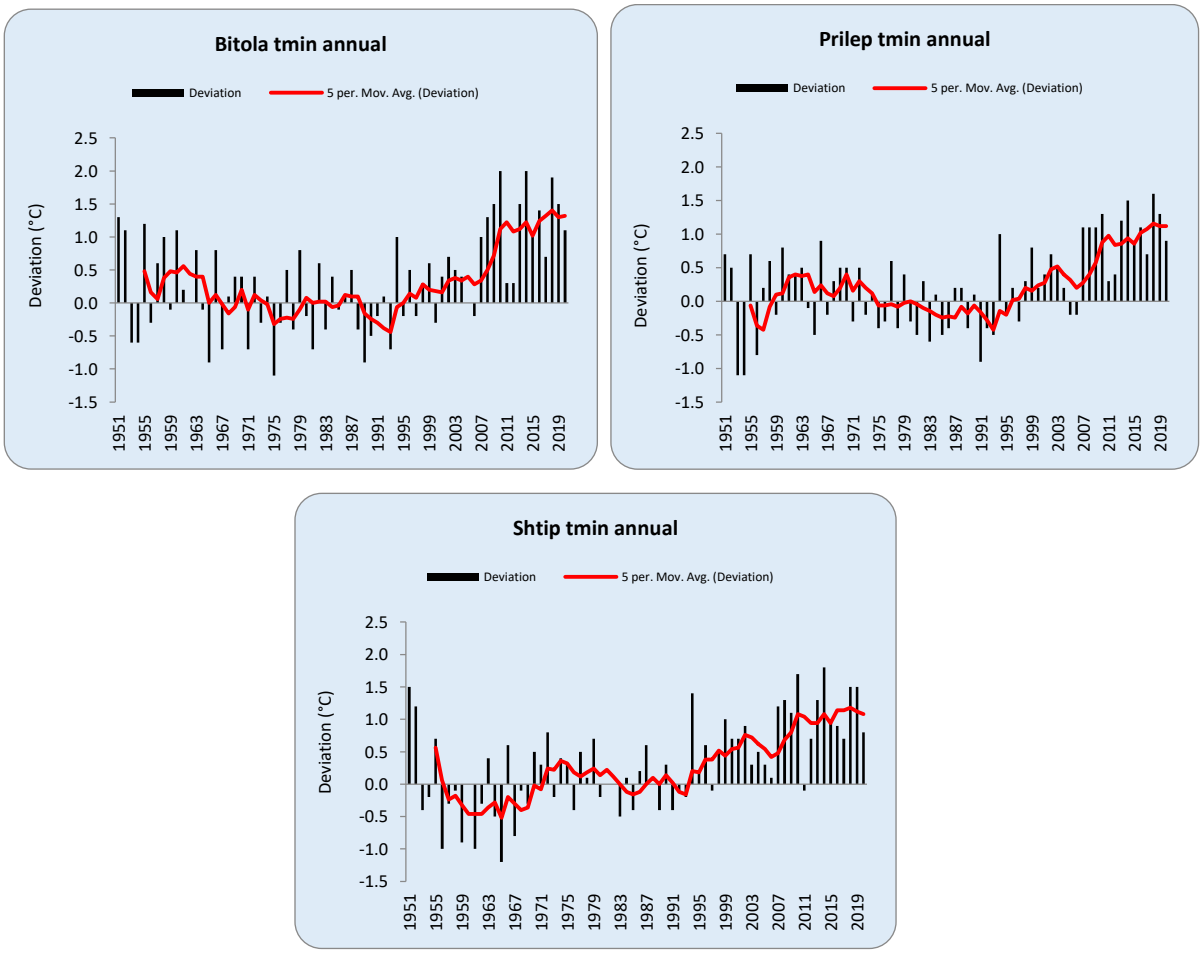
Graph 5. Deviation of the winter air temperature from the average for the period 1961 -1990

The analysis of the mean annual maximum and minimum air temperature for the period 1951-2020 shows an increasing trend. The increase in the maximum temperature is larger than the increase in the minimum temperature (Graphs 6 and 7). The difference of the average values for the period 1951-2020 compared to the average for the period 1961-1990 ranges from 0.1°C to 0.4°C for the minimum temperature and from 0.5°C to 0.7°C for the maximum temperature.





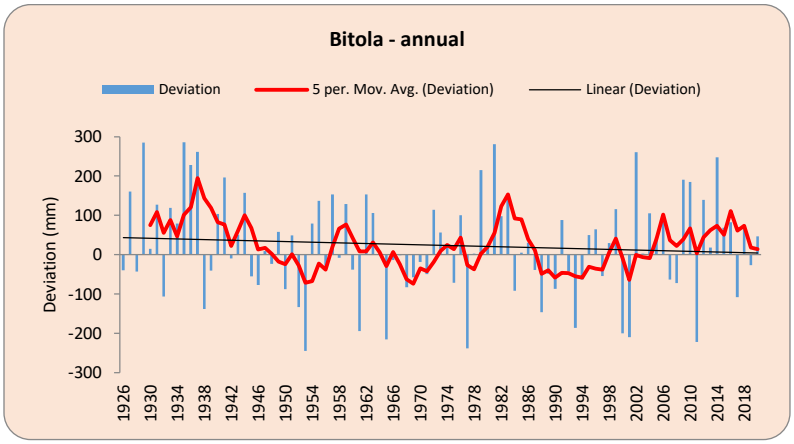
Graph 6. Deviation of the mean annual maximum air temperature from the average for the period 1961 -1990

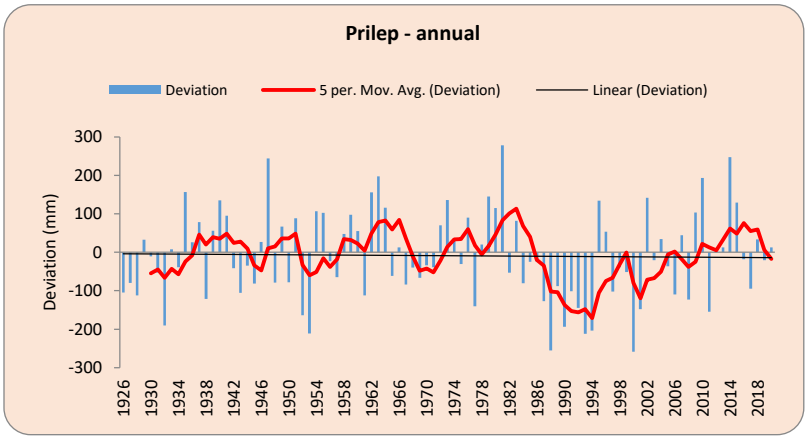


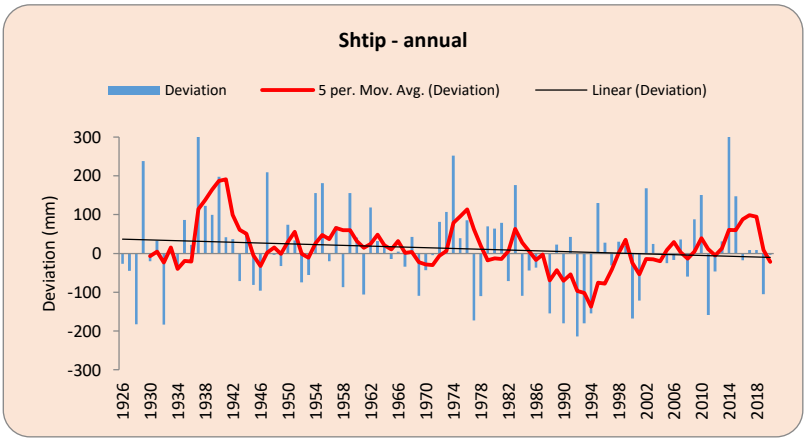
Graph 7. Deviation of the mean annual minimum air temperature from the average for the period 1961 -1990

2. CLIMATE VARIABILITY OF PRECIPITATION

The analysis of the annual and seasonal precipitation for the previously mentioned meteorological stations was performed in an identical way. The multi-year change in the annual sum of precipitation (Graph 8) indicates a general trend of decrease in precipitation, however, due to the rapid changes in the amount of precipitation from year to year, the level of the decrease cannot be explicitly determined.





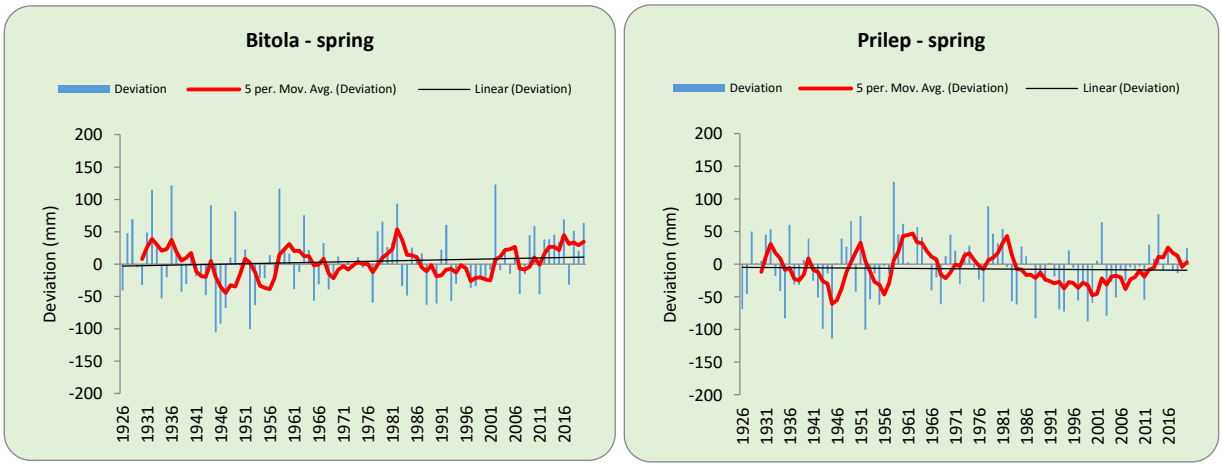


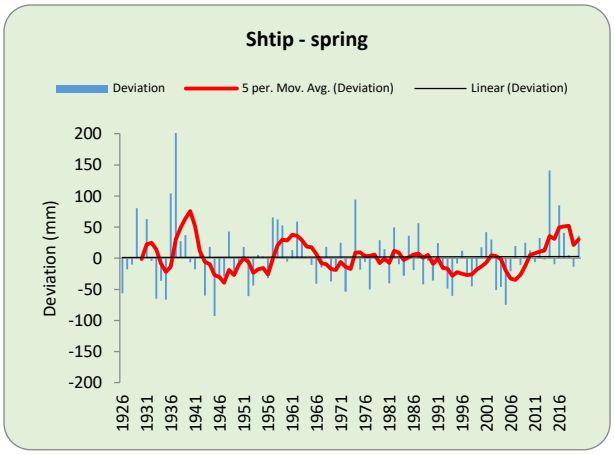
Graphs 8. Deviation of the annual sum of precipitation from the average 1961-1990

The decrease of precipitation in the last forty years compared to the period 1961-1990 on an annual level is especially pronounced in the period from 1987 to 1994, as well as in 2000, 2001 and 2011. The driest years for the period 1951-2020 and also years for which most meteorological stations recorded the largest deviations of precipitation from the average are 1993, 2000 and 2011. It is characteristic that in the years between these periods, annual recorded sum of precipitation was higher than the average values, and 2014, 2010 and 2002 stand out. Absolute daily maximum precipitation for the period 1951-1990 is 201.0 mm and was recorded in Gevgelija on June 5, 2004, and the largest monthly sum of precipitation (389.6 mm) was measured in November 1985 at the meteorological station Lazaropole.

From the multi-year variation of the seasonal precipitations shown in graphs 9, 10, 11 and 12, a decrease in the autumn and winter precipitations is evident, while for the spring and summer the trend of the variations cannot be generally determined. The trend of the spring sum of precipitation for Bitola shows an increase, while for Prilep and Shtip a decrease, and the trend of the summer sum of precipitation for Bitola shows a decrease in the precipitation unlike Prilep and Shtip.

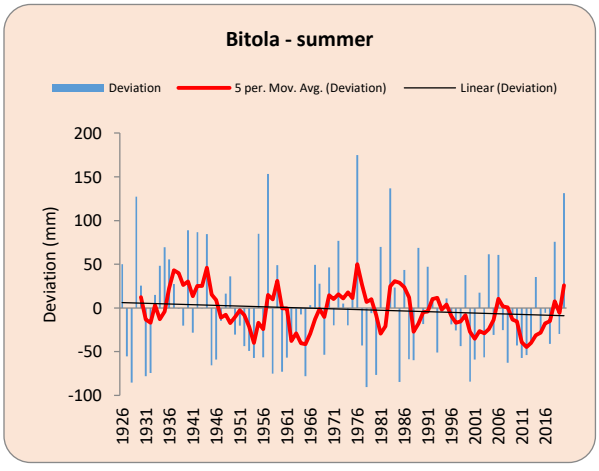
Characteristic of the spring sum of precipitation is that the last decade 2010-2020 has the highest average decadal value compared to other decades for the period 1951-2020. In this period 2012, 2014 and 2016 are the years that have the five highest values of the spring sum of precipitation recorded at most of the meteorological stations.

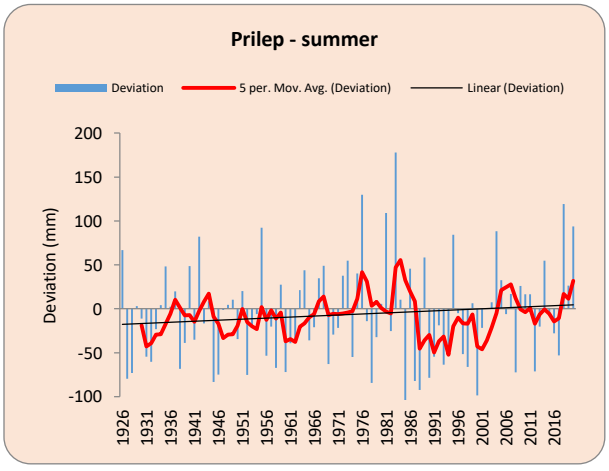


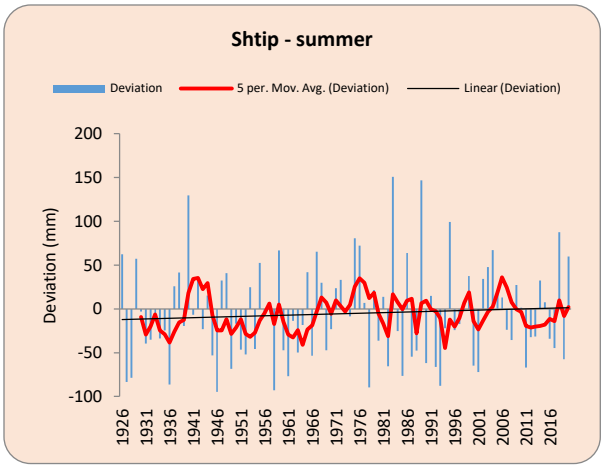


Graph 9. Deviation of the spring sum of precipitation from the average 1961-1990

The change of seasonal sum of precipitation throughout the year can be best noticed in the extreme seasonal sum of summer and autumn precipitation. In the five years with the highest values of the summer sum of precipitation for the period 1951-2020, for Bitola and Prilep 2020 stands out, and for Berovo 2020 is the year with the highest value of the summer sum of precipitation. Characteristic for the extreme values of the autumn sum of precipitation is that 2020 for the meteorological stations Bitola, Prilep, Demir Kapija, Gevgelija, Berovo and Ohrid is in the range of years with the five lowest values of the autumn sum of precipitation (period 1951-2020).

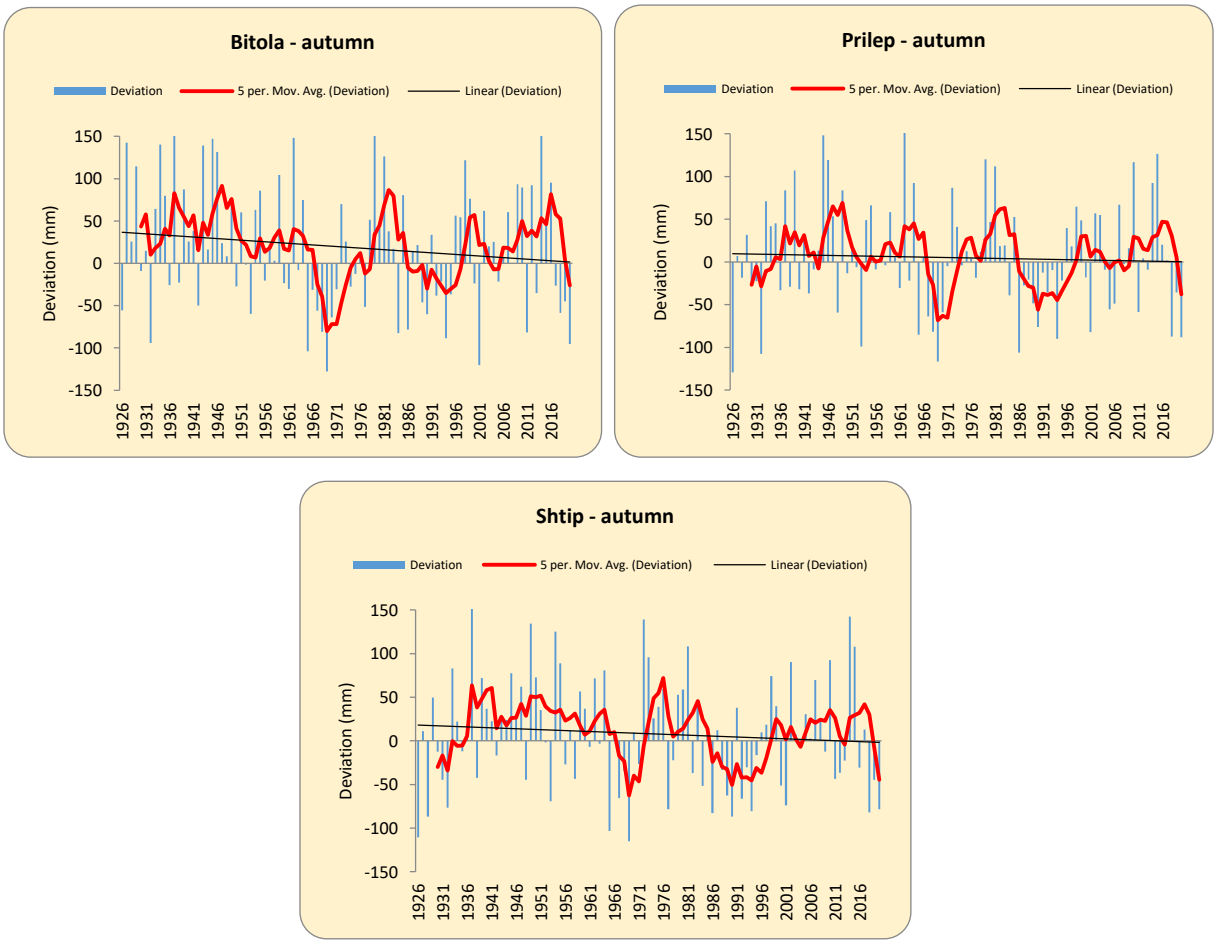




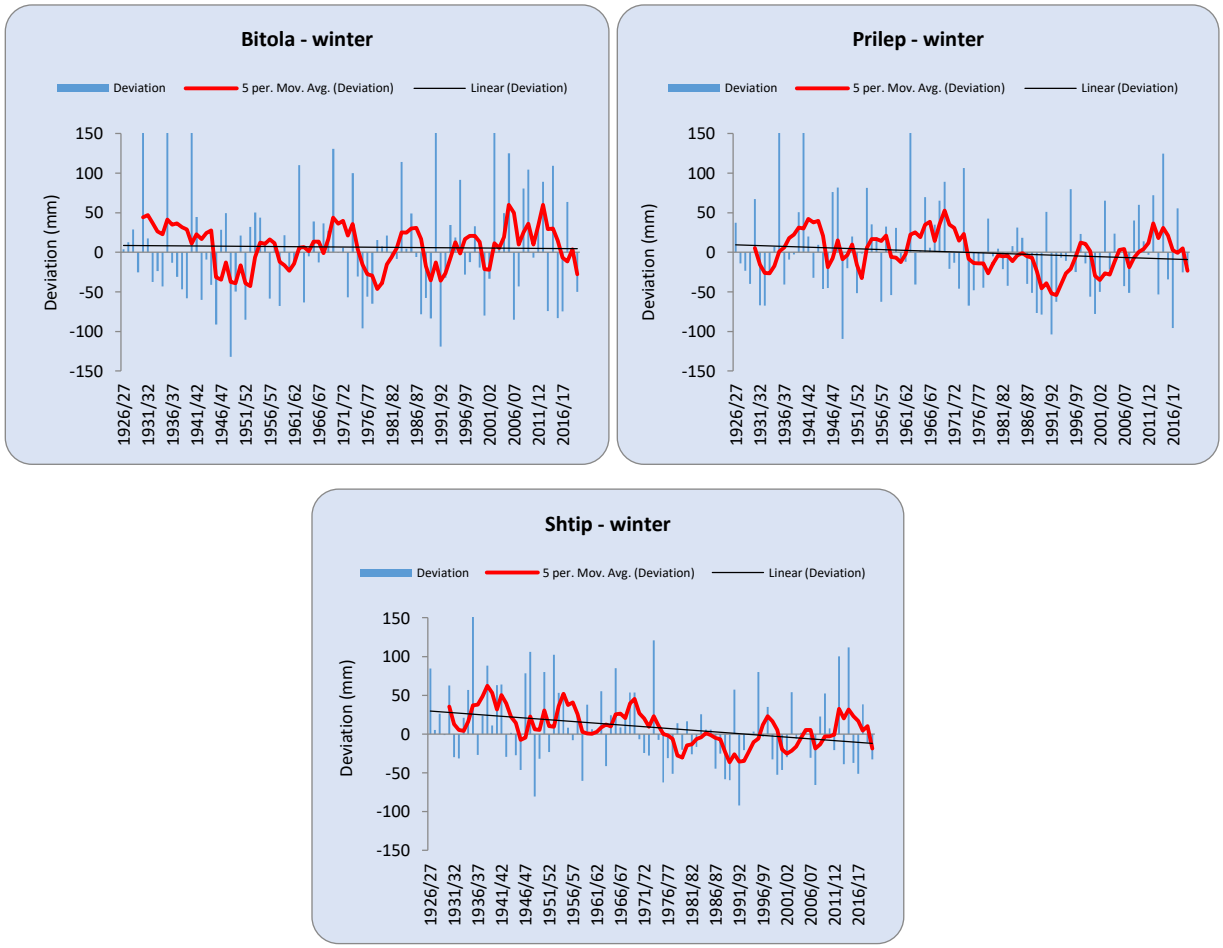


Graphs 10. Deviation of the summer sum of precipitation from the average 1961-1990

The most extreme year with the lowest sum of winter precipitation (period 1951-2020) for all stations is 1991/1992. The interannual change of the extreme seasonal sum of precipitation is noticed in the winter sum of precipitation for Bitola and Strumica where 1990/1991 stands out as the winter with the highest value of the sum of precipitation.



Graph 11. Deviation of the autumn sum of precipitation from the average 1961-1990



Graph 12. Deviation of the winter sum of precipitation from the average 1961-1990

3. ANALYSIS AND INTERPRETATION OF CLIMATE DATA SERIES FOR THE PERIODS 1961-1990, 1971-2000, 1981-2010 AND 1991-2020 AND COMPARISON THEREOF

When analyzing climate variability and climate change, the analysis of data for the thirty-year periods 1971-2000, 1981-2010 and 1991-2020 and their comparison with the reference thirty-year period 1961-1990 is of great importance. Also, by analyzing the differences of the decadal data in comparison to the period 1961-1990, important conclusions are reached with regard to the change in the values of climatic elements and climatic indices. In continuation we present the analysis on air temperature, precipitation and snow cover.

3.1 AIR TEMPERATURE

The analysis of the spatial distribution of the changes in the air temperature is shown through the deviations of the average annual and seasonal temperature for the periods 1971-2000, 1981-2010 and 1991-2020 and the decadal averages for the period 1951-2020 in relation to the

reference thirty-year period 1961-1990. In the past fifty years, the largest deviation of the average annual temperature from the average for 1961-1990 is in the period 1991-2020 (Figure 1).

During the period 1991-2020, the average annual temperature is higher on the whole territory in the range of 0.7°C to 1.4°C. Higher values were also observed for the period 1981-2010 (0.2°C-0.8°C), while for the period 1971-2000 the annual temperature is within the average values for the period 1961-1990. The analysis of deviations of average seasonal temperatures from the average for 1961-1990 also show that the highest values are in the period 1991-2020, with the largest increase in the summer temperatures with deviations ranging from 1.2°C to 2.2°C.

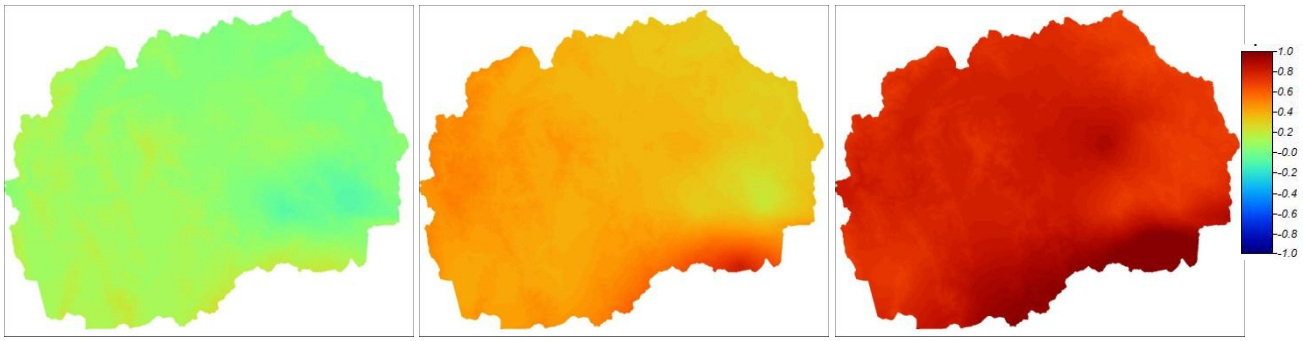
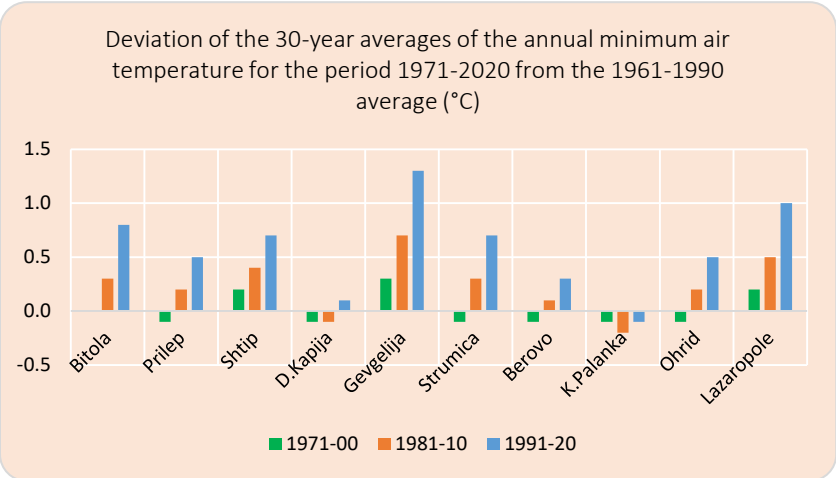
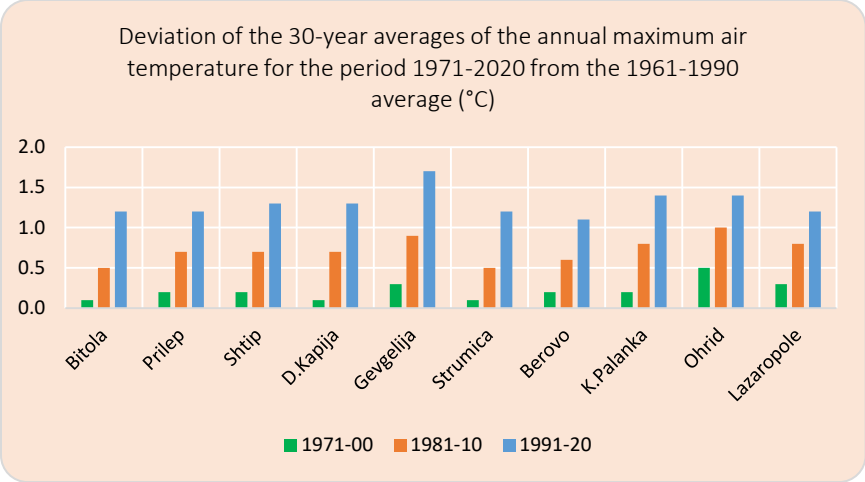


Figure 1. Deviation of the 30-year averages of the annual air temperature (1971-2000, 1981-2010 and 1991-2020) from the average for 1961-1990

Similar conclusions are reached by analyzing the values of mean minimum and maximum temperatures for the same periods. The change in mean minimum temperature is less than the change in mean maximum temperature. The deviations of the mean minimum temperature for the period 1991-2020 compared to the reference period range from -0.1°C to 1.3°C, while the deviations of the mean maximum temperature range from 1.1°C to 1.7°C (Graphs 13 and 14).

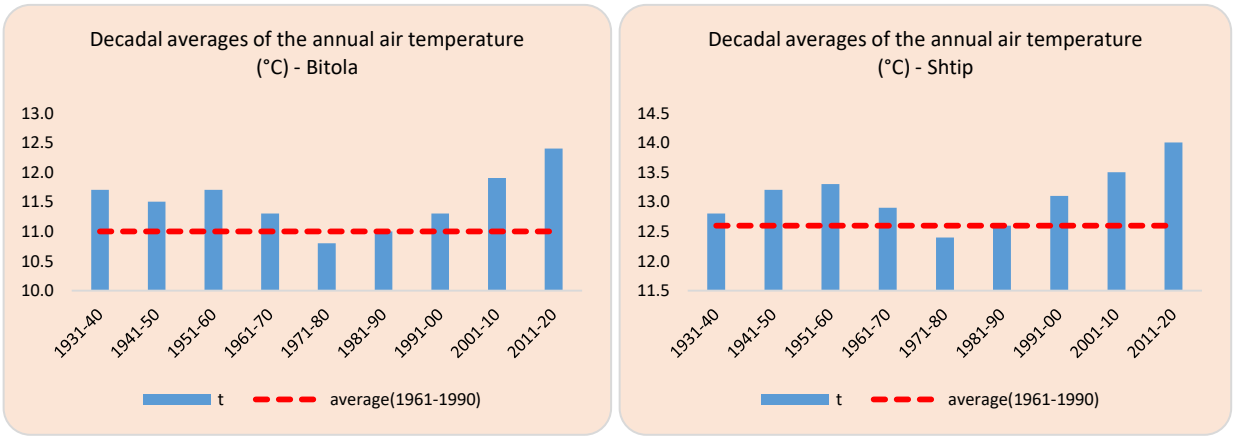


Graph 13. Deviation of the 30-year averages of the annual minimum air temperature for the period 1971-2020 from the 1961-1990 average



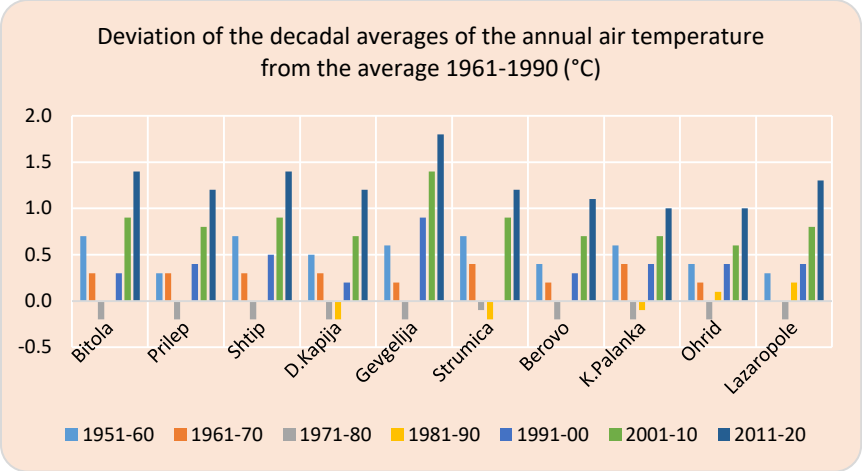
Graph 14. Deviation of the 30-year averages of the annual maximum air temperature for the period 1971-2020 from the 1961-1990 average

Research conducted on the decadal averages of the annual air temperature shows that the last decade (2011-2020) is the warmest decade since the beginning of meteorological measurements on the territory of the Republic of North Macedonia (Graph 15).



Graph 15. Deviation of the decadal averages of the annual air temperature for the period 1931-2020 from the average 1961-1990

In this decade, nine years (2012-2020) are in the rank of the seven highest values of the annual air temperature for the period 1951-2020, and for the meteorological stations Gevgelija, Demir Kapija, Strumica, Shtip and Lazaropole 2019 is the warmest year so far. The deviations of the decadal value for 2011-2020 compared to the average for 1961-1990 range from 1.0°C to 1.8°C (Graph 16). The last decade (2011-2020) is the warmest also on a seasonal level with the largest deviation from the average of the summer season (1.3°C-2.5°C). For the winter period, the decade 1951-1960 stands out, for which the values of the annual air temperature are similar to the decade 2011-2020.



Graph 16. Deviation of the decadal averages of the annual air temperature for the period 1951-2020 from the average 1961-1990

3.2 PRECIPITATION

Precipitation does not have a pronounced and unambiguous trend in the spatial and temporal analysis as is the case with the variations in air temperature. The analysis of the annual sum of precipitation shows a decrease for the period 1971-2000 compared to the reference period, values around the average for the period 1981-2010 and an increase in the annual amount of precipitation at most meteorological stations for the period 1991-2020 (up to 6%).

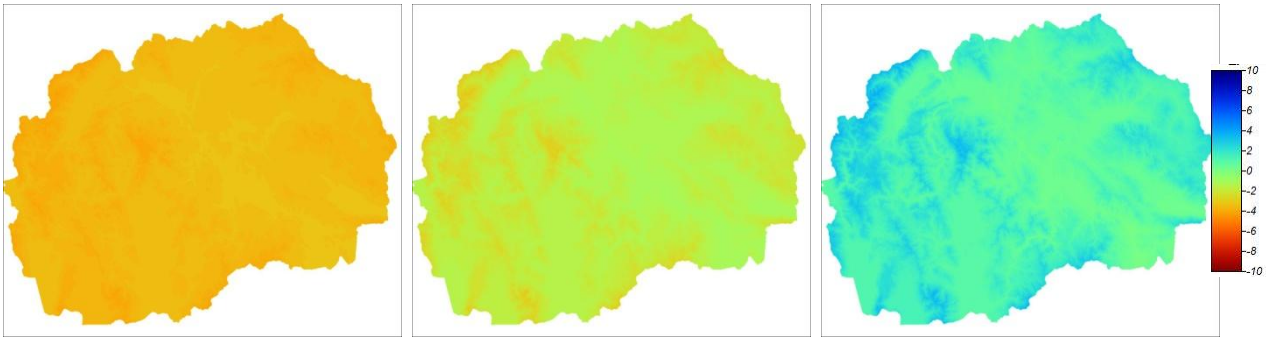
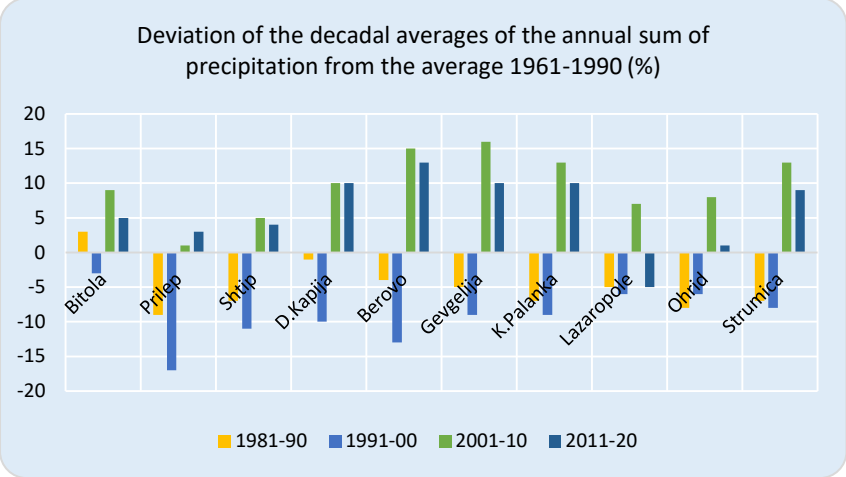


Figure 3. Deviation of the 30-year averages of the annual sum of precipitation (1971-2000, 1981-2010 and 1991-2020) from the average for 1961-1990

From the seasonal sums of precipitation, the most characteristic is the autumn sum with a positive deviation from the average for all three periods, and the largest is for the period 1991-2020 (1-11%). The amount of spring precipitation is generally below average for all periods, with the exception of the period 1991-2020 for the meteorological stations Bitola, Shtip, Demir Kapija, Berovo, Kriva Palanka and Ohrid, where an increase in precipitation was observed (2-7%). Increase in precipitation for the summer season was observed for Strumica, Lazaropole Berovo and Gevgelija (up to 7%) for the period 1981-2010 and for Kriva Palanka, Gevgelija, Strumica, Demir Kapija and Berovo (up to 12%) for the period 1991-2020 . In the winter season, the deviations from the average 1961-1990 are below the average for the period 1971-2000,

while for the other periods different deviations were noticed. Higher than average values are observed for Demir Kapija, Kriva Palanka, Ohrid, Bitola, Strumica and Gevgelija for the period 1981-2010 (2-11%) and in Demir Kapija, Berovo, Ohrid, Strumica, Bitola and Gevgelija for 1991-2020 (2-16%).

Analyses done on the decadal averages of the annual sum of precipitation show a decrease in precipitation for the two consecutive decades 1981-1990 and 1991-2000 compared to the average 1961-1990 (up to 17%), followed by two decades 2001-2010 and 2011-2020 with higher than average precipitation (Graph 17). In these decades there are a larger number of years that are in the range of years with higher annual sum of precipitation, with 2014, 2010 and 2002 standing out which are in the group of several most extreme years. It is evident that the wettest decade is 2001-2010 with an increase in the annual sum of precipitation of up to 16% compared to the average and for most meteorological stations for the autumn season with an increase of up to 30%. Increase of precipitation at all meteorological stations compared to the reference period was registered with regard to the spring sum of precipitation for the decade 2011-2020 (4% -24%).

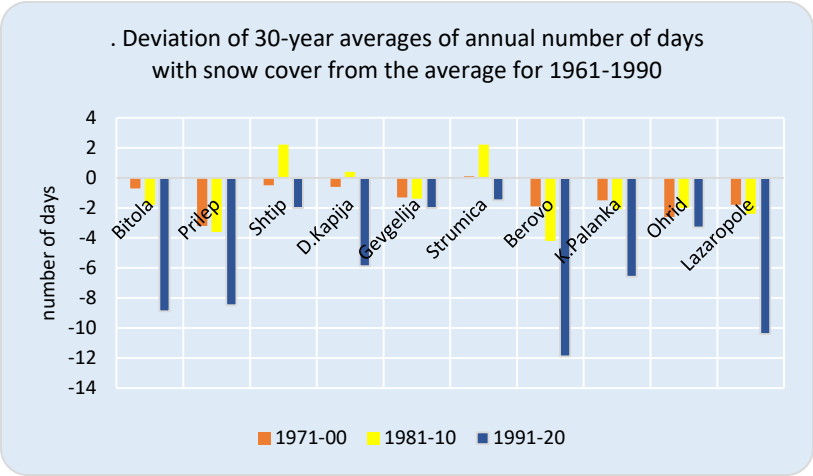


Graph 17. Deviation of the decadal averages of the annual sum of precipitation from the average for the period 1961-1990 (%)

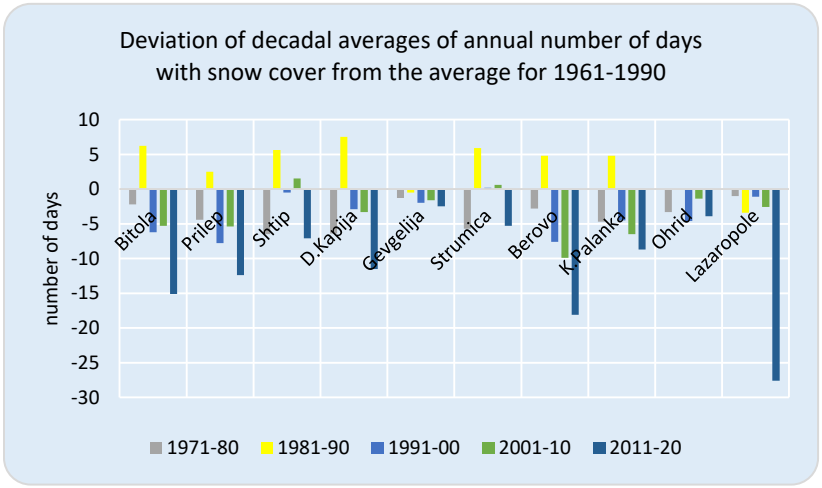
3.3 SNOW AND SNOW COVER

Snow and snow cover are analyzed through the number of days with snow cover on a decadal and a thirty-year level (Graphs 18 and 19). There is a decrease in the annual number of days with snow cover compared to the average for the period 1961-1990 for all three periods 1971-2000, 1981-2010 and 1991-2020 (Graph 18), with a slight increase for the meteorological stations Shtip and Strumica for the period 1971-2000. The largest decrease in the annual number of days with snow cover (from 3 to 12 days) is registered for the period 1991-2020. In the last 4 decades, the annual number of days with snow cover has decreased compared to the

average, and the largest decrease (from 3 to 28 days) is registered for the decade 2011-2020 (Graph 19).



Graph 18. Deviation of 30-year averages of annual number of days with snow cover from the average for 1961-1990



Graph 19. Deviation of decadal averages of annual number of days with snow cover from the average for 1961-1990

3.4 CLIMATE INDICES

The analysis of temperature indices shows how much the observed increase in air temperature affects the decrease in frequency and duration of cold and increase in hot periods, which can cause adverse effects. In the past fifty years, the largest decrease in the average annual number of frost days (days when the minimum air temperature is lower than 0°C) and the number of icing days (days when the maximum air temperature is lower than 0°C) compared to the average for 1961-1990 is registered in the period 1991-2020. During this period on the territory of the country there was a decrease in frost days from 1 to 17 days, with the exception of

meteorological stations Demir Kapija and Kriva Palanka where an increase of 2 and 4 days was observed. Icing days are less common than frost days so their reduction compared to the reference period is lower (from 1 to 4 days).

The same thirty-year period also saw the largest increase in the average annual number of tropical nights (days when the minimum air temperature is higher than 20°C) and the average annual number of summer days (days when the maximum air temperature is higher than 25°C) in comparison to the reference period. Tropical nights are a rarer occurrence that in some places at higher altitudes such as Berovo and Lazaropole has not been observed at all in the past. The largest increase in tropical nights of 18 days was observed at the meteorological station Gevgelija, while for the other stations Bitola, Prilep, Strumica, Demir Kapija and Shtip the increase is from 1 to 5 days. The increase of the summer days is from 11 to 24 days, so the biggest deviation from the reference period is noticed at higher altitude.

Research conducted on the decadal averages shows that the largest change in the annual number of frost days, icing days, summer days and tropical nights compared to the reference period was observed in the last decade (2011-2020). Frost days have reduced from 3 to 23 days, and icing days up to 8 days. The biggest decrease, especially in the number of frost days, was observed at the meteorological station Lazaropole. The largest increase in tropical nights of 28 days was observed at the meteorological station Gevgelija, while for the other stations Bitola, Ohrid, Prilep, Strumica, Demir Kapija and Shtip the increase is from 1 to 6 days. The increase of summer days on the entire territory of the country is greater than 18 days, and the largest increase of 28 days was observed in Berovo and Kriva Palanka.

With regard to risks for various sectors caused by high air temperatures, the frequency and duration of the excessive or prolonged heat during the year is especially important. The duration index of a warm period (spell) is calculated with the number of days with at least 6 consecutive days when the maximum daily temperature is greater than the 90th percentile for the calendar day calculated for a five-day window centered on each calendar day for the reference period 1961-1990. The largest increase in the frequency and in the number of days with heat spells annually compared to the reference period is in the period 1991-2020 and in 2011-2020. In the period 1991-2020, the annual increase is from 9 days (in Prilep) to 20 days (in Gevgelija), while in 2011-2020 the increase for the entire territory of the country is more than 14 days with heat spells. In the last decade in Demir Kapija and Strumica there has been an increase of 30 days, and in Gevgelija even 41 days more compared to the reference period.
For proper growth and development of plants, in addition to the previously mentioned temperature indices, the growing season length is of particular importance. The length of the growing season is defined by the number of days between the beginning of the first period with at least 6 days with daily mean temperature higher than 5°C and the beginning of the first

period in the second half of the year with daily mean temperature lower than 5°C. The largest extension of the growing season length compared to the reference period was observed for the period 1991-2020 with a maximum of 16 days in Gevgelija. A slight decrease in the length of the growing season was observed in Demir Kapija and Berovo, where the growing season was shorter for 2 and 4 days. Research conducted on the decadal averages shows that in the last decades, 2001-2020 and 2011-2020, the largest change in the length of the growing season was observed. During the last ten years, a shorter and longer extension of the growing season has been recorded. The largest extensions of 21 days and 22 days were observed in Lazaropole and in Gevgelija. Greater length of the vegetation period was observed in the period 2001-2010 when the length of the growing season in the whole country was extended by more than 10 days, with a maximum of 23 days in Bitola, Gevgelija, Shtip and Demir Kapija and 24 days in Strumica. The only reduction in the growing season length of 5 days was observed in Berovo.

The analysis of precipitation indices shows a change in the precipitation regime with an increase in the frequency of heavy and very heavy precipitation. Days with heavy precipitation are days during which the daily quantity of precipitation is greater or equal to 10mm, while days with very heavy precipitation are those during which the daily quantity of precipitation is greater or equal to 20 mm. In the last 30-year period, in most meteorological stations there is an increase in the number of days with heavy and very heavy precipitation for 1 day to 2 days, in comparison to the reference average. In the last two decades there is an increase in the number of days with heavy and very heavy precipitation for 3 (2001-2010) and 4 days (2011-2020) on the whole territory of the country, with the exception of Lazaropole, where this number has been reduced for 1 (2001-2010) and 2 days (2011-2020).