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Climate Model–Based Projections of Maximum Temperature Change in Northwestern Libya for the Period 1961–2099 Using Data from Misurata Airport Meteorological Station

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ABSTRACT:

The Global Climate Model (GCM) is one of the key tools used in studying the characteristics of future temperature trends. This study aims to project future maximum temperatures for the period 2010–2099, based on observed maximum temperature data from the Misrata Airport Meteorological Station during the baseline period (1961–1990). The projections were conducted using the Statistical Downscaling Model (SDSM), relying on two widely recognized climate change scenarios: A2a and B2a. These scenarios were adopted by the Intergovernmental Panel on Climate Change (IPCC) in the Special Report on Emissions Scenarios (SRES, 2000), which provides future projections for climate and environmental conditions based on greenhouse gas emissions The results revealed that eight predictor variables from the GCM have a significant influence on the maximum temperature at Misrata Airport station. Additionally, the findings indicated that the SDSM effectively simulates annual and monthly maximum temperature variations with reasonable accuracy for the validation period (1991–2000). The analysis also demonstrated a clear trend of increasing monthly, seasonal, and annual maximum temperatures in future periods compared to the baseline period.

Keywords: Climate Projections, Climate Change, Maximum Temperature, Climate Model, SDSM, GCM..

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بناء السيناريوهات المستقبلية لتغير درجة الحرارة العظمى في شمال غرب ليبيا للفترة (1961 – 2099) باستخدام النماذج المناخية محطة أرصاد مطار مصراتة أنموذجا.

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الملخص

يُعدّ نموذج المناخ العالمي (GCM) من الأدوات المستخدمة في دراسة خصائص درجات الحرارة المستقبلية، من خلال التنبؤ بدرجات الحرارة العظمى مستقبلاً للفترة (2010 – 2099)، بالاعتماد على درجة الحرارة العظمى لمحطة أرصاد مطار مصراتة لفترة الأساس (1961 –1990) بواسطة تقنية ((Statistical Downscaling Model (SDSM))، اعتماداً على سيناريوهات التغير المناخي (A2a) و (B2a) ؛ وهي سيناريوهات معتمدة لدى الفريق المعني بالتغير المناخيIPCC في تقرير عرف بـSRES في سنة 2000 لوضع توقعات للمناخ والبيئة بالاعتماد على غازات الاحتباس الحراري.

حيث أظهرت النتائج أن هناك ثمانية عناصر من النموذج العام هي التي تؤثر في درجة الحرارة في محطة أرصاد مطار مصراتة، كما أظهرت النتائج كذلك أن (SDSM) يحاكي التغير في درجة الحرارة العظمى السنوية والشهرية بدقة جيدة للفترة من 1991–2000، كما بينت النتائج وجود اتجاه واضح للتغير في مقدار درجات الحرارة الشهرية والفصلية والسنوية للفترات المستقبلية مقارنة بفترة الأساس.

الكلمات الدالة: سيناريوهات المناخ / التغير المناخي/ درجة الحرارة العظمى/ النموذج المناخي/ SDSM/ GCM.

Introduction:

Climate change does not manifest uniformly across the globe; rather, its direction—whether toward warming or cooling—varies from one region to another. Research has shown that the extent of climate change is more pronounced in higher latitudes compared to

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lower latitudes, with the northern hemisphere experiencing more intense changes than the southern hemisphere [علي أحمد غانم ،2013 ص281.] for several decades, scientists have expressed concern over the rising global temperatures caused by irresponsible human activities, such as the burning of fossil fuels, intensive agriculture, and deforestation. The 20th century witnessed a noticeable rise in temperature, particularly during the 1990s, which was recorded as the warmest decade in the past millennium, with an increase of more than half a degree Celsius.

Studies have further confirmed that the increase or decrease in temperature cannot be entirely explained by natural climate variability alone [IPCC, 2001, p31]. This is evident when comparing observed global temperature data with simulations generated by General Circulation Models (GCMs). These models are widely used in the study of global warming by integrating model outputs with observed temperature data from specific study stations. However, due to the relatively coarse spatial resolution of GCMs in predicting future changes in climatic elements, downscaling techniques have emerged as a solution to bridge large-scale atmospheric variables with localized climatic variables [Laprise, R., D, 1998.p44]

Climate projections now allow us to estimate potential future climatic conditions based on the likelihood of certain scenarios—such as increases in greenhouse gas concentrations—that are expected to significantly affect future [Canada as Simulated.p119]. climate characteristics. Climate scenarios have become an essential tool for illustrating what future climate conditions might look like. They rely on global climate models (GCMs), which serve as a fundamental method for analyzing climate variability across the past, present, and future. These models are grounded in physical laws that govern climatic processes and interaction [World Meteorological Organization, 2001. P6-10]

It is well established that the global average surface temperature—over both land and ocean—has increased since the late 19th century. The last three decades have been the warmest in the instrumental climate record, particularly the year 2000, which was recorded as one of the hottest years on rec [Intergovernmental Panel on Climate Change2013, p. 37]

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Significance of the Study :

1. This study highlights the importance of one of the statistical techniques specialized in projecting future climate variables
2. It evaluates the extent of change in maximum temperature at the Misrata Meteorological Station throughout the 21st century based on proposed climate change scenarios.
3. It contributes to enhancing climate future studies in Libya.

Study objectives:

1. To assess the ability of the Statistical Downscaling Model (SDSM) in generating a time series of local maximum temperature data for the Misrata Meteorological Station.
2. To investigate the future behavior of maximum temperature in the Misrata region, based on simulations of key global climate models and their associated future scenarios for the period 2019–2099.
3. To quantify the magnitude of change in maximum temperature throughout the study period and to identify the degree of seasonal and annual variability.

Statement of the problem:

1. Is it possible to construct future projections of maximum temperature in Misrata using the SDSM technique؟
2. Is there a trend in monthly, seasonal, and annual maximum temperature values throughout the study periods when compared to the baseline period؟
3. What is the behavior of the projected increase in maximum temperature for the period 2010–2099 under scenario A2a versus scenario B2a؟
4. What is the degree of variation in maximum temperature rates at the monthly, seasonal, and annual levels in Misrata؟

Hypotheses

1. It is possible to generate future projections of maximum temperature in Misrata using the SDSM technique, provided that the observed station data match the modeled data for the reference period.
2. Maximum temperature rates are expected to increase compared to the baseline period through to the year 2099.

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3. The future behavior of maximum temperature in the Misrata region is more consistent with the pessimistic scenario A2a than with scenario B2a.
4. 4. the Misrata station vary throughout the study period–1961) .(2099

Study Area:
The study area is Misrata, located in northern Libya, adjacent to the Mediterranean Sea to the north. It is bordered by Bani Walid to the south, Sirte to the east, and Zliten to the west. The Misrata Meteorological Station is situated in the city center and is geographically located at latitude 32.406310°N and longitude 15.033092°E, as shown in Figure(1).

Fig. (1): The Study Area
Source: Prepared by the researcher using GIS, based on the National Atlas (1978, p. 25).

Methodology of the Study:
This study employed a statistical analytical approach, utilizing daily maximum temperature averages from the Misrata Meteorological Station, as provided by the Libyan National Meteorological Center for the baseline period (1961–1990). These data served as the

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foundation for future simulations and modeling for the period 2010–2099 using the Statistical Downscaling Model (SDSM). The SDSM is a tool designed to support decision-making processes related to future temperature projections. It is based on outputs from the General Circulation Model (GCM)—a numerical model that integrates physical interactions among land surfaces, oceans, ice, and the atmosphere [RICCAR Partners 2017, p 37] .
The study relied on emission scenarios to analyze climate change trends throughout the 21st century using the Hadley Centre Coupled Model version 3 (HadCM3), developed by the Hadley Centre of the UK Met Office. HadCM3 is a globally recognized coupled climate model that has been widely used for climate prediction, detection and attribution studies, and sensitivity analyses. It was developed in 1999 and has been extensively applied over the past two decades in numerous studies of past and future climate change. This model was one of the core models used in the IPCC's Third and Fourth Assessment Reports, and it also contributed to the Fifth Assessment Report in 2014. One of HadCM3's major advancements at the time of its development was its ability to simulate present-day climate conditions without requiring flux adjustments, placing it among the most reliable models for climate projection. Moreover, it has demonstrated strong capacity to capture the time-dependent fingerprint of historical climate change in response to both natural and anthropogenic forcings, making it particularly valuable for detection and attribution studies .[أسمهان علي عثمان، 2023، 102]

The study adopted two climate scenarios:

•Scenario A2a: This scenario describes a highly heterogeneous world, emphasizing self-reliance and regional economic development. It assumes significant regional differences in fertility patterns, resulting in continuously increasing global population and higher population densities. Economic growth is regional and uneven.

•Scenario B2a: This scenario is oriented toward global solutions for economic, social, and environmental sustainability. It assumes continuous but slower population growth than A2a, moderate economic development, and less rapid but more diverse technological change. The scenario also emphasizes the use of alternative energy and achieving social and economic equity, along

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with reducing the intensity of resource us [Intergovernmental Panel on Climate Change, 2000.p33]

The first topic: The Statistical Downscaling Model (SDSM) and Its Application in Predicting Maximum Temperatures:

The Statistical Downscaling Model (SDSM) is one of the techniques adopted by the Intergovernmental Panel on Climate Change (IPCC). It is used to handle climatic data related to various elements for the purpose of assessing the regional impacts of climate change and supporting decision-making concerning future climate projections and anticipated climate shifts. The model also facilitates the evaluation of local climate statistics and their influence on climate change. Through this software, multiple scenarios are employed to help determine present and future daily, monthly, and annual climatic variables.[جمعة المليان واخرون، 2021، ص37]
SDSM relies on simulations derived from global models, particularly General Circulation Models (GCMs) and Regional Climate Models (RCMs). These models serve as input for analyzing and identifying the strength of relationships among various climatic variables, to determine which variables exert the greatest influence on future projections of maximum temperature at the Misrata Meteorological Station.
In this study, the variables influencing climate—according to the GCM—were selected based on their correlation with maximum temperature. These variables are presented in Table.(1)

Table (1) Prediction variables for climate scenarios.

No	Predictor variables	predictor description	No	Predictor variables	predictor description
1	mslpaf	mean sea level pressure	14	p5zhaf	500hpa divergence
2	p_faf	surface air flow strength	15	p8_faf	850hpa air flow strength
3	p_uaf	surface zonal velocity	16	p8_uaf	hpa zonal 850velocity
4	p_vaf	Surface merdional velocity	17	p8_vaf	hpa meridional 850velocity
5	p_zaf	surface vorticity	18	p8_zaf	850 hpa vorticity
6	p_thaf	surface wind direction	19	p850af	850hpa geopotential height

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No	Predictor variables	predictor description	No	Predictor variables	predictor description
7	p_zhaf	surface divergent	20	p8thaf	850hpa wind direction
8	p5_faf	hpa airflow 500strength	21	p8zhaf	850hpa divergence
9	p5_uaf	hpa zonal 500velocity	22	pr500af	Relative humidity at 500hpa
10	p5 _vaf	hpa merdional 500velocity	23	pr850af	Relative humidity at 850hpa
11	p5_zaf	500hpa vorticity	24	rhumaf	Near surface relative humidity
12	p500af	hpa geopotential 500height	25	shumaf	Surface specific humidity
13	P5thaf	hpa wind 500direction	26	tempaf	Mean temperature at 2 meter

Source: Wilby and Dawson (2007) p. 17.

The program involves working through six stages, starting with verifying data accuracy through the Quality Control icon, up to Summary Statistics, which is the final stage summarizing the forecast data statistically [Wilby, R. L. and Dawson,2007]. The stages are listed below in order:

1 – Data Quality Control
2 – Screen Variables
3 – Calibrate Model
4 – Weather Generation
5 – Scenario Generation
6 – Summary Statistics

In the Quality Control stage, the daily maximum temperature data were verified and checked for consistency with the numerical values of the baseline period (1961–1990), representing 10,957 days. Missing and incomplete values were identified and treated, and outliers were adjusted.

In the second stage, the strength of predictor variables such as elevation above sea level and atmospheric pressure values, which vary by place and time, was examined. The correlation between the maximum temperature at Misrata Meteorological Station and the 26 variables listed in Table (1) was identified. It was found that eight out of the 26 variables have a strong correlation with the simulation of the maximum temperature for Misrata Station — see Table (2).

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The relationship between geographic elevation at 500 meters and relative humidity at 2 meters above ground level with the maximum temperature at Misrata Station showed the highest correlation values of (0.568, 0.554) respectively, as shown in Figure.(2) .

Table (2) shows the eight variables of the GCM model that are related to the maximum temperature at the Misurata Weather Station.

ranking	Code	N	R-NCCCSM
12	p500af	hpa geopotential height500	0.568
25	shumaf	Surface specific humidity	0.554
26	tempaf	Mean temperature at 2 metre	0.528
24	rhumaf	Near surface relative humidity	0.281
19	p850af	hpa geopotential850	0.261
4	p_vaf	Surface merdional velocity	0.244
17	p8_vaf	hpa meridional velocity850	0.158
6	p_thaf	surface wind direction	0.11

Source: The researcher's work is based on: SDSM4.2.9.

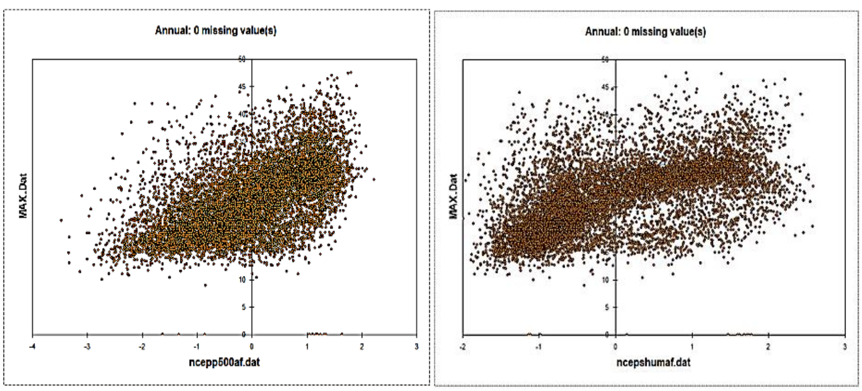

Figure (2) shows the correlation between the maximum temperatures of Misrata with the two variables (12/25).
Source: Researcher work based on: SDSM4.2.9

Before starting the modeling of future maximum temperature for the study periods (2010–2039), (2040–2069), and (2070–2099) for the Misrata Meteorological Station, the third stage involved calibrating the simulation model by comparing the observed data from Misrata Station during the period (1991–2000), obtained from the National Center for Meteorology, with the results of the modeling process using the SDSM technique for the same period. It was found that the

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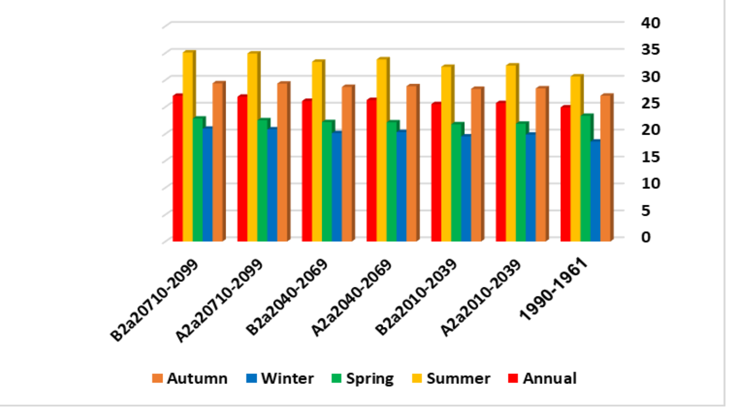
annual data from both sources matched closely, which is evidence of the modeling accuracy, even though there were discrepancies at the seasonal level due to differences in data between the two sources during some months only. The cause of the mismatch in the other months is attributed to measurement inaccuracies or incomplete data recording by observers at the station, who relied on personal estimates. See Figure (3).



Figure(3). Calibration of the model temperature at the Misurata Meteorological Station for the period (1991-2000)
Source: Researcher work based on meteorological data and SDSM4.2.9

The second topic: Changes in Maximum Temperatures at Misrata Meteorological Station during the Period (1961 – 2099 AD).

First: Changes in Monthly Maximum Temperatures according to Scenarios B2a and H3A2a.

1-Changes in Monthly and Annual Maximum Temperatures according to Scenario H3A2a:

The results in Table (3), figure (4) and Figure(5) show a comparison of the average maximum temperature during the baseline period (1961–1990) with the maximum temperature during the modeling periods extending from 2010 to 2099 based on scenario H3A2a. It is observed that there is a clear change in the monthly and annual average maximum temperatures at Misrata Station during the modeling periods.

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In the first and second modeling periods (2010–2069), the average increase in the first period is about 0.8°C, and the increase in the second period is estimated at about 1.4°C compared to the baseline period (1961–1990). Meanwhile, the increase in the third period is about 2°C above its average in the baseline period.

Table (3) Future Projections of the Monthly Maximum Temperature at Misrata Meteorological Station according to H3A2a Scenario.

Month	Monthly Average -1990 1960	2010-2039		2040-2069		2070-2099	
		Monthly Average	change amount	Monthly Average	change amount	Monthly Average	change amount
September	30.7	30.6	-0.1	30.8	0.1	26.2	1.2
October	27.4	28.9	1.4	29.2	1.8	24.7	2.0
November	23.2	25.9	2.7	26.6	3.4	24.2	3.6
December	19.1	21.9	2.9	22.7	3.6	23.3	3.9
January	17.7	19.3	1.6	19.7	2.0	21.8	2.8
February	19.0	18.3	-0.6	18.6	-0.4	24.3	0.1
March	20.7	19.1	-1.6	19.4	-1.3	28.3	-1.2
April	23.3	20.9	-2.4	21.1	-2.2	31.8	-2.1
May	26.1	25.7	-0.5	25.9	-0.2	32.3	0.8
June	29.4	31.7	2.3	32.8	3.4	30.5	4.5
July	30.8	34.3	3.5	35.6	4.7	27.3	6.3
August	31.7	32.1	0.3	33.2	1.4	27.4	2.0
Average	24.9	25.7	0.8	26.3	1.4	26.9	2.0

Source: Researcher's work based on SDSM4.2.9.

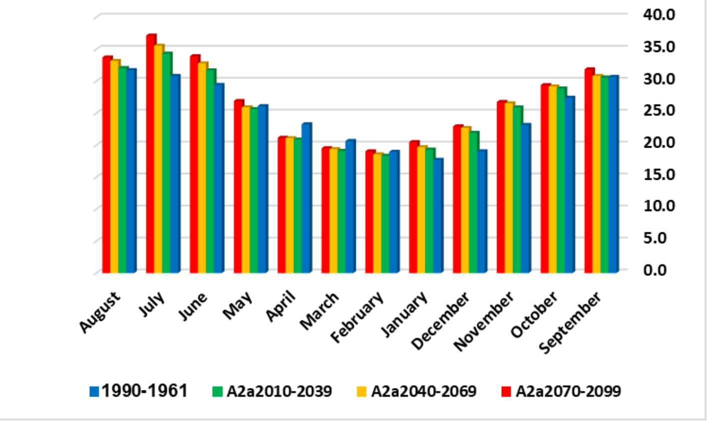

Figure (4) Maximum temperature averages at Misurata weather station for the three modeling periods according to H3A2a scenario.

Source: The work of the researcher based on Table (3)

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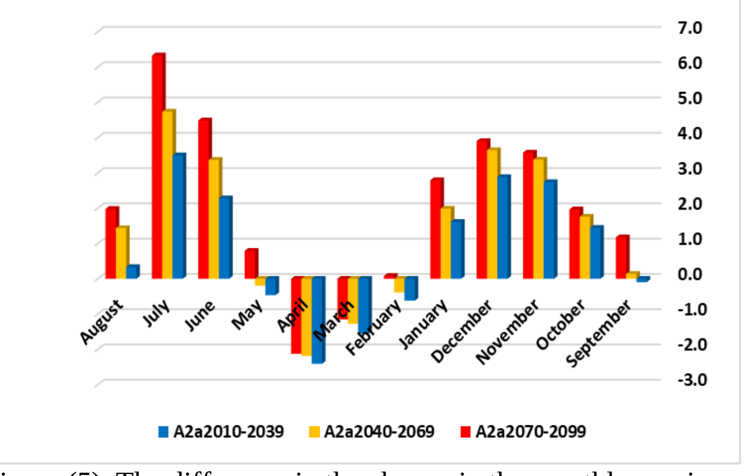

Figure (5). The difference in the change in the monthly maximum temperature rates at the Misurata weather station in the modeling .periods according to the H3A2a scenario

Source: The work of the researcher based on Table (3). As shown in Figure (3), the Misrata

Meteorological Station is expected to experience an increase in temperature above the average during the period (2010–2099). Most of the monthly maximum temperature data under scenario H3A2a show a general upward trend in most months of the year, except for February, March, April, and May, which are expected to experience decreases compared to the baseline period. The decreases range between 0.6°C in February and 2.4°C in April.

2 -Changes in Monthly Maximum Temperatures according to Scenario H3B2a:

The results of the maximum temperature modeling at Misrata Station according to scenario H3B2a indicate that the annual average will tend to increase, similarly to the previous scenario. The peak increase is expected to reach 27.1°C during the period (2070–2099), which is an increase of 2.2°C above its annual average of 24.8°C in the baseline period (1961–1990), as shown in Table (4), figure (6) and figure(7).

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Table (4) Future Projections of the Monthly Maximum Temperature at Misrata Meteorological Station According to H3B2a Scenario

Month	Monthly Average -1990 1960	2010-2039		2040-2069		2070-2099	
		Monthly Average	change amount	Monthly Average	change amount	Monthly Average	change amount
September	30.7	30.4	-0.3	30.7	0.0	31.4	0.7
October	27.4	29.0	1.5	29.2	1.8	29.5	2.1
November	23.2	25.7	2.6	26.3	3.1	27.3	4.1
December	19.1	21.5	2.4	22.2	3.2	23.5	4.5
January	17.7	18.9	1.2	19.6	1.9	20.4	2.7
February	19.0	18.2	-0.8	18.6	-0.4	19.0	0.0
March	20.7	19.4	-1.3	19.6	-1.1	19.6	-1.1
April	23.3	20.8	-2.5	20.9	-2.4	21.6	-1.7
May	26.1	25.1	-1.0	26.1	0.0	27.4	1.2
June	29.4	31.4	1.9	32.2	2.8	34.1	4.7
July	30.8	34.0	3.1	35.3	4.4	37.4	6.5
August	31.7	32.0	0.3	32.7	1.0	33.9	2.2
Average	24.8	25.5	0.6	26.1	1.2	27.1	2.2

Source: Researcher's work based on SDSM4.2.9.

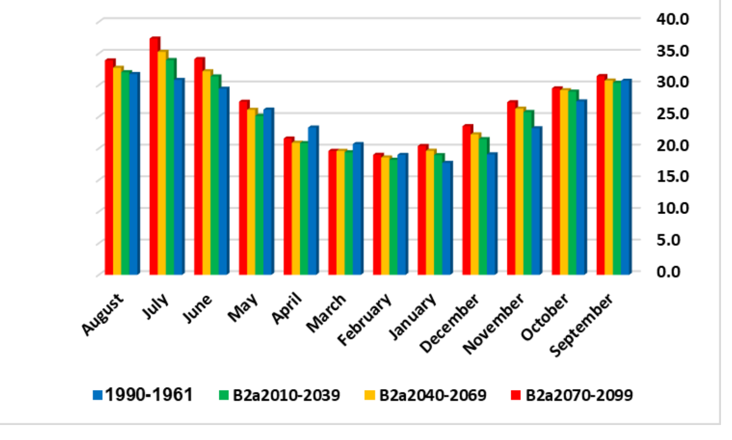

Figure (6). Maximum temperature projections for future periods according to H3B2a scenario

Source: The work of the researcher based on Table (4).

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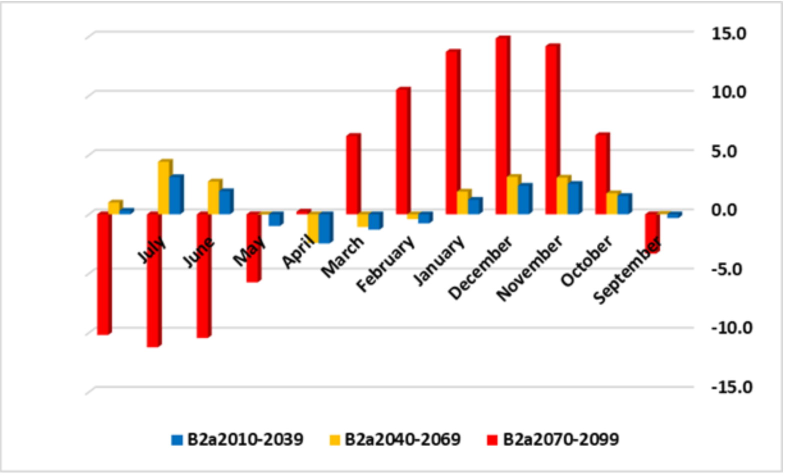

Figure (7). The difference in the change in the monthly maximum temperature rates in the Misurata weather station in the modeling periods according to the H3A2a scenario.

Source: The work of the researcher based on Table.

Second: Changes in Seasonal Maximum Temperatures according to Scenarios H3A2a and H3B2a:

The results of Table (5) and Figure (8) confirmed that there is an increase in the average maximum temperature during the seasons of autumn, winter, and summer in the future periods (2010–2099) by approximately 1°C. Meanwhile, spring temperatures show a decreasing trend, with a drop of about 1°C compared to the baseline period (1961–1990), as illustrated in Figure(9).

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Table (5) Future projections of the quarterly and annual maximum tractor degree according to the H3A2a/H3B2a scenario At Misrata Weather Station.

Season	1961-1990	2019-2045		2046-2072		2073-2099	
		A2a	B2a	A2a	B2a	A2a	B2a
Autumn	27.1	28.5	28.4	28.9	28.7	29.3	29.4
Winter	18.6	19.9	19.5	20.3	20.1	20.8	21
Spring	23.4	21.9	22.2	22.1	22.2	22.5	22.8
Summer	30.7	32.7	32.5	33.8	33.4	34.9	35.1
Annual	25	25.8	25.7	26.3	26.1	26.9	27.1

Source: The researcher's work based on tables (3,4).

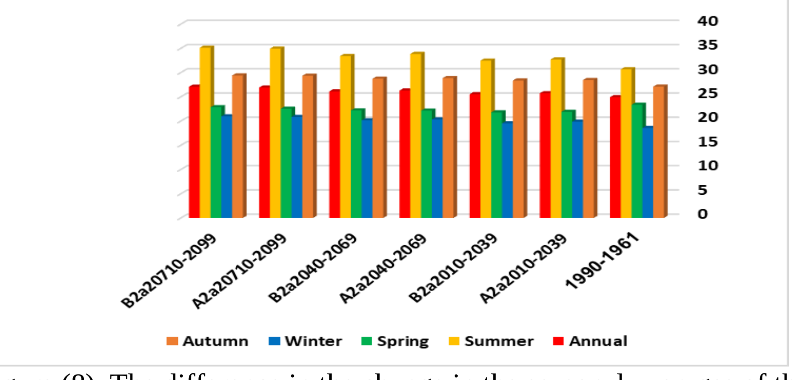

Figure (8). The difference in the change in the seasonal averages of the maximum temperature in the Misurata weather station in the modeling periods according to the H3A2a/H3B2a scenario.
Source: The work of the researcher based on Table (5).

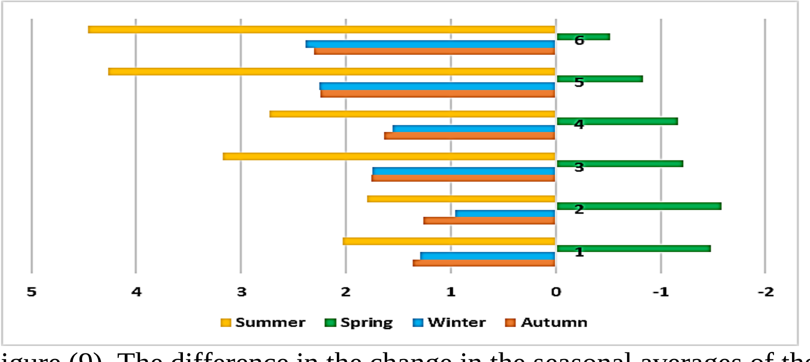

Figure (9). The difference in the change in the seasonal averages of the maximum temperature in the Misurata weather station in the modeling periods according to the H3A2a/H3B2a scenario.
Source: The work of the researcher based on Table (5).

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Findings:

1. The results confirmed that the maximum temperature at Misrata Meteorological Station has a strong correlation with eight out of 26 variables from the GCM model. The relationship between geographic elevation at 500 meters and relative humidity at 2 meters above ground level with the maximum temperature at Misrata Station showed the highest correlation values of (0.568 and 0.554), respectively.
2. The results also showed a match between the annual data of Misrata Station and the data modeled by the SDSM, which indicates the accuracy of the modeling, even if not identical at the seasonal level. The mismatch in some months is due to differences between the data sources, which is attributed to measurement inaccuracies or incomplete data recording by station observers, often relying on personal estimates.

3. By comparing the average maximum temperature during the baseline period (1961–1990) with that during the modeling periods (2010–2099) based on scenario H3A2a, a clear change is observed in the monthly and annual averages. In the first and second modeling periods (2010–2069), the average increase is about 0.8°C in the first period and 1.4°C in the second period compared to the baseline. The increase rises to approximately 2°C in the third period.
4. The modeling results for maximum temperatures at Misrata Station based on scenario H3B2a also indicate a general upward trend, similar to the previous scenario. The peak increase is expected to reach 27.1°C during the period (2070–2099), which is 2.2°C higher than the baseline annual average of 24.8°C (1961–1990), as shown in Table.(4).
5. The seasonal scenario results confirmed an increase in the average maximum temperature during autumn, winter, and summer in the future periods (2010–2099) by about 1°C, while

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spring temperatures are expected to decline by approximately 1°C compared to the baseline period (1990–1961).

Recommendations:

1. There is a need to raise awareness about the dangers of climate change impacts
2. Necessary measures should be taken to mitigate the serious effects of climate change in the country by supporting research projects across all sectors, as they are of strategic importance in preventing many problems and losses — particularly in health and agricultural sectors, which are directly affected by climate change.The National Center of Meteorology in Tripoli should provide daily data from all weather stations in the country to serve researchers in the fields of climate and climate change.
3. Efforts should be made to train meteorological staff and weather/climate specialists in using such techniques, in order to produce seasonal and annual climate forecasts for the country.

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