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Estimation of Future Temperature Change in Misurata Area-Libya by Using Statistical Downscaling Method (SDSM)

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Abstract: There is much discussion in the scientific literature and concern in the wider community about climate change, recent climate analyses indicate that the magnitude of 21st Century warming is likely to have been the largest of any century for the last 1000 years over the northern hemisphere. All the IPCC's four reports between 1990 and 2007 concluded that we cannot expect stable climate in the future and we should prepare scenarios and strategies for the survival of humankind under the conditions of forthcoming global change. In this study, the applicability of the statistical downscaling model (SDSM) in downscaling temperature in Misurata area - Libya, was investigated. The investigation includes the calibration of the SDSM model by using large-scale atmospheric variables encompassing NCEP reanalysis data, the validation of the model were measured daily temperature data (1961-1990) using independent period of the NCEP reanalysis data and the general circulation model (GCM) outputs of scenarios A2 and B2 of the HadCM3 model. The model is calibrated and applied at a daily time series, even though the output is monthly and the prediction of the future regional maximum and minimum temperature scenarios for three time windows: 2011-2040, 2041-2070 and 2071-2099. The results showed that: The statistical downscaling model (SDSM) was able to describe the basic statistical properties of daily minimum and maximum temperature in the period of record, suggesting that it could be used to predict future trends. Trend analysis in the study area showed an increase in average annual and monthly temperature, compared to the baseline period for both HadCM3A2a and HadCM3B2a scenarios in both the dry and wet seasons. However, this increase is higher in dry months than wet months for all future time horizons and for both HadCM3A2a and HadCM3B2a scenarios. Thus there is likely to be a significant warming in local surface temperature, which is enough for a significant change on the energy balance and is likely to impact water availability.

Key words: Statistical downscaling model · SDSM · Intergovernmental Panel on Climate Change IPCC · General circulation model · GCM · Special Report on the Emission Scenarios · SERS · Maximum and minimum temperature · Misurata area · Libya

INTRODUCTION

Climate change has already become a global issue, which needs to turn the minds of every one caring for the future. There is much discussion in the scientific literature and concern in the wider community about climate change, the subject of global warming has initiated this investigation concerning temporal changes of extreme temperatures in Europe and North of Africa, recent climate analyses for the last 1000 years over the northern hemisphere indicate the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850), it also Indicate that the magnitude of 21st Century warming is likely to have been the largest of any century during this period. Numerous studies, Jones *et al.* [1] Arnell [2] IPCC. [3, 4]. Indicates that the mean annual global surface temperature has increased by 0.3-0.6°C since the late 19th century, they all pointed to the fact that there is a general upward (warming) trend in the global mean surface temperature and it is expected to further increase by 1-3.5°C over the next 100 years. Such changes in the climate will have significant impact in the ecological, social and economical system.

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All the IPCC's four reports between 1990 and 2007 reports concluded that we cannot expect stable climate in the future and we should prepare scenarios and strategies for the survival of humankind under the conditions of forthcoming global change. However, they acknowledge that there are major uncertainties in projected climate change impacts on natural resources, under different scenarios of economic development, greenhouse gas emissions, climate modelling and hydrological modelling.

Nevertheless, substantial differences are observed in the regional change in climate compared to global mean change [5].

Climate model scenarios are dynamic mathematical models that simulate the physical processes of the atmosphere and oceans in order to predict future global and regional climate. The general circulation models (GCM) are the most complex of these models and the most powerful tools available for making realistic estimates of climate change. However, they involve much uncertainty, especially in terms of estimating regional or local change essentially with reference to the extremes Gibelin and Déqué [6] and Pope *et al.* [7].

Climate scientists use downscaling techniques that take output from the GCMs and add information at scales smaller than the grid spacing. In this study the Statistical Downscaling Models (SDSM) of maximum and minimum daily temperature for Musrat station in Libya are predicted for different scenarios of climate change for three time windows: 2011-2040, 2041-2070 and 2071-2099.

The HadCM3 model is selected for this study since the model is widely used for climate change impact assessment. For the SDSM the 30 years historic data of maximum and minimum daily temperature of Musrat station were used.

Objective of the Study: In this study the general circulation model (GCM) output of HadCM3 to predict the future climate variables and statistical downscaling model (SDSM) to change the coarse resolution of climate variables to the finer scale are used to estimate the future maximum and minimum daily temperature for Musrat station in Libya.

Specific Objectives of this Study Are:

- To compare the HadCM3 output of maximum air temperature and minimum air temperature with observed trends from the weather station records.
- To determine the future trends of maximum air temperature and minimum air temperature up to 2099 for Musrat station in Libya.

Study Area: Musrat is located in North West of Libya along the southern Mediterranean coast. The area extends between 31° 33' and 32° 23' N and 14° 36' to 15° 22' E encompassing a geographical area of 3637km2 within which 60% is semi arid area (Fig. 1).

The elevation ranges from -15 m to 65 m. The climate is generally described as semi-arid to arid, with hot and dry summers and moderate winters with rainfall.

The mean annual temperature varies given the fact that the north of the study area corresponding to the Mediterranean Sea is milder 19°C compared to the south 20°C.

Data and Methods

Statistical Analysis of Observed Data: To analyze the trends of observed maximum temperature, minimum temperature data of Musrat station, statistical analyses are considered. For this study significance testing using confidence intervals of least square is applied for analyzing the temperature change for the time period 1961-1990 for which daily observations are available.

First a simple linear regression model of $\hat{y}_i = a + bx_i$ is selected and then it is tested whether *b* is significantly different from zero. In the linear model a is the constant value of temperature and *b* is the change per year (slope), x_i| is a year to which the output is calculated by the model and $\hat{y}_i$ | is the estimated temperature by the linear model.

The variance is calculated by:

$$\sigma^2 = \frac{\sum((y_i - (a + bx_i))^2}{N - 2}$$

where

σ = Variance in $(°C)^2$ for temperature

y_i = The observed time series data °C for temperature

$a + bx_i$ = The output of the linear model °C for temperature

N = sum of observation years.

- The observed years from the above equation it can be shown that the regression coefficient *b* will have the student-*t* distribution with variance.

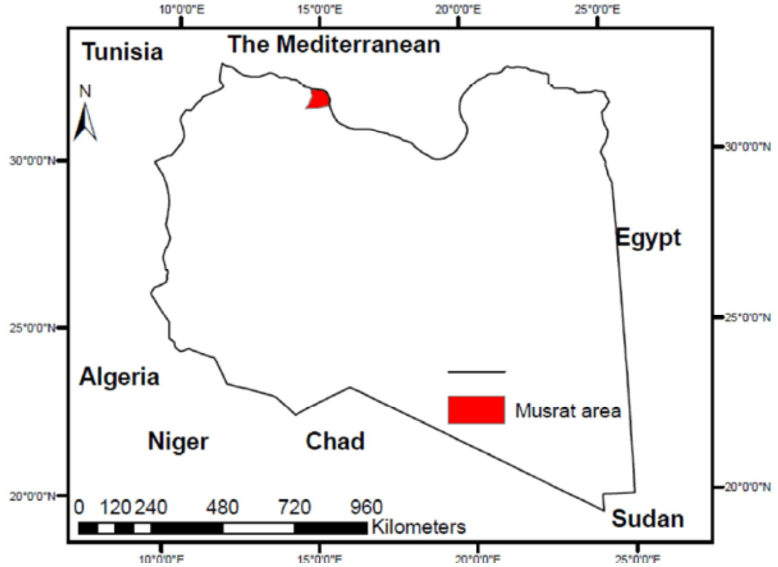

Fig. 1: Location of the Musrat area

$$\operatorname{var}[b] = \frac{\sigma^2}{\sum\left(x_i - \bar{x}\right)^2}$$

Based on the variance of b, the t distribution table is used to define the multiplier t for the confidence limits for the regression coefficient under the hypothesis of no climate change.

$$b = \beta \pm t\sqrt{\operatorname{var}(b)}$$

For t test analysis the slope β is equal to some specified value β_0 (often assumed as 00. This is because it has to be tested that there is climate chang ($\beta \neq 0$) and the hypothesis that there is no climate shange ($\beta = 0$). Therefore based on this it is possible to estimate the current climate change with a specified confidence interval.

General Circulation Model: Among the different GCMs the HadCM3 model is selected for this study since the model is widely used for climate change impact assessment. Besides this the model is selected due to the availability of the downscaling models called SDSM that is used to downscale the result of HadCM3. For HadCM3 the model result is available for A2 and B2 emission scenario, where A2 is refereed to as medium-high emission scenario and B2 is medium-low emission scenario. For both scenarios the ensemble members a, b and c are available which refer to a different initial point of climate solution along the reference period [8]. But for this study the data is available for the "a" ensembles and hence only the A2a and B2a scenarios are considered.

Statistical Downscaling Model (SDSM): The selected regression based method is the SDSM 4.2 developed by Dowson and Wilbey [9]. It is a decision support tool used to assess local climate change impacts using a statistical downscaling technique. The tool facilitates the rapid development of multiple, low cost, single site scenarios of daily surface weather variables under current and future climate forcing.

The model is calibrated and applied at a daily time series even though the output is at monthly basis.

The software manages additional tasks of data quality control and transformation, predicator variable screening, automatic model calibration, statistical analysis and graphing of climate data.

Downloading the Predictors: One of the basic advantages of this approach is that it is computationally less expensive and it can be easily applied to different GCM scenarios [10]. The HadCM3 simulation is a coupled atmosphere- ocean general circulation model (AOGCM) developed at the Hadley Centre-UK and described by Gordon *et al.* [11] and Pope *et al.* [7].

The atmospheric component of HadCM3 has 19 levels with a horizontal resolution of 2.58 latitude by 3.758 longitude; The time-domain for the HadCM3 daily simulations is from Jan 1 1961 to Dec 31 2099 (30 times 360 days per year).

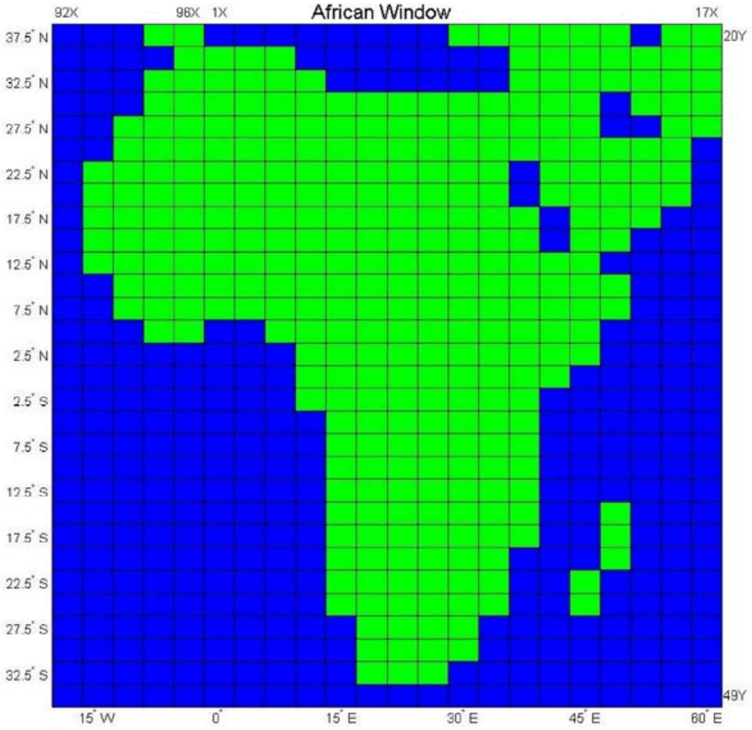

Fig. 2: Location of grid cells for statistical downloading

Table 1: Predictor variables of the 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	850 hpa zonal velocity
4	p_vaf	Surface merdional velocity	17	p8_vaf	850 hpa meridional velocity
5	p_zaf	surface vorticity	18	p8_zaf	850 hpa vorticity
6	P_thaf	surface wind direction	19	p850af	850 hpa geopotential
7	p_zhaf	surface divergent	20	p8thaf	850 hpa wind direction
8	p5_faf	500hpa airflow strength	21	p8zhaf	850hpa divergence
9	p5_uaf	500hpa zonal velocity	22	pr500af	Relative humidity at 500hpa
10	p5_vaf	500hpa merdional velocity	23	pr850af	Relative humidity at 850hpa
11	p5_zaf	500hpa vorticity	24	rhumaf	Near surface relative humidity
12	p500af	500hpa geopotential height	25	shumaf	Surface specific humidity
13	p5thaf	500hpa wind direction	26	tempaf	Mean temperature at 2 metre

Source: Wilby and Dawson [12]

The NCEP Reanalyses (National Centre for Environmental Prediction USA), which are currently available and contain several meteorological parameters in a global spatial resolution of 2.5-2.58 latitude longitude, the NCEP Reanalysis data is from Jan 1 1961 to Dec 30 2001 (30 times 365 days per year).

The nearest grid box which represents the study area is between 13o 12’ 05” E to 15o 09’ 01” (centred on 15° 00’ 00” E) and 31°25’00”N to 33°08’00”N (centred on 32°30’00”N) (Figure 2 and Table 1).

The model is calibrated and applied at a daily time series even though the output is monthly. The predictor variables used for the SDSM model input were downloaded from the Canadian Institute for Climate Studies website for model output of HadCM^3.

This data is used for calibration of the SDSM with the actual maximum temperature, minimum temperature.

Preparation of Predictands: The maximum temperature and minimum temperature records from 1961-1990 of have been prepared for inputs to the statistical downscaling model.

In the time series data there are some outliers, missing data and gap data that should be corrected before it can be used in the model. The outliers are the values that highly deviate from the mean value. The missing data and gap data are less than 43% for maximum temperature and minimum temperature of the total data available from the meteorological station.

Model Parameters: In the SDSM before doing any analysis the first step is fixing the model parameters which are basic to the temperature simulation. Maximum temperature and minimum temperature are continuous processes. Therefore no event threshold is required for maximum temperature and minimum temperature. A statistical method is more straightforward than dynamic downscaling but tends to underestimate variance and poorly represent extreme events.

Regression method under predict climate variability to varying degrees, since only parts of the regional and local climate variability is related to large scale climate variations. The range of variation of the downscaled and daily weather parameters can be controlled by fixing the variance inflation. This parameter changes the variance by adding /subtracting equal amount applied to regression model estimates of the local process.

Then variance inflation of 12 prior to any model transformation produces normal variance inflation for daily temperature values. The choice of statistical method is to some extent determined by the nature of the local predictand.

A local variable that is reasonably normally distributed, such as temperature will require nothing more complicated than multiple regression, since the large scale climate predictors are normally distributed and assuming linearity of the relationship.

Screening Downscaled Predicator Variables: Screening is identifying the downscaled predicators, which have high correlation with the actual climate variable. The method correlates each predictands (observed maximum and minimum temperature) with the 26 NCEP downloaded predictors data.

The strength of the individual predictors varies on a month by month basis. Therefore most appropriate combination of predictors has to be chosen by looking at the analysis output of the twelve months. The predicators, which have significant correlation with each predictands and low correlation with the individual predictors should be selected for calibration. The predictor variables selected for maximum temperature for each downscaling process conducted in this study are: meansed level pressure, surface vorticity, 850 hpa meridional velocity, near surface relative humidity and mean temperature at 2m.

The predictor variables selected for minimum temperature for each downscaling process conducted in this study are: 500 hPa zonal velocity, 500 hPa geopotential height and Relative humidity at 850 hPa, Surface specific humidity and Mean temperature at 2m.

Model Calibration: The calibration of the statistical downscaling model is based on the multiple linear regressions between the screened predictors and the predictand. Twelve multiple linear regression equations for each months are produced automatically between the predictand and the screened predictors.

For model calibration, the predictands of daily maximum temperature and minimum temperature of the station are used. The calibration is done based on the 30 year actual data from 1961-1990 since this period is the baseline period for most climate change impact assessment.

In calibration of the SDSM the process type that identifies the presence of the intermediate process in the predictor-predictand relationship must be defined. In unconditional process there is the direct link between the predicator and the predictand (e.g., maximum and minimum temperature are directly depends on mean temperature at 2 metre height).

In unconditional process the predictand and predictors are correlated with automatic calibration method without any intermediate process. Therefore unconditional process is used for maximum and minimum temperature.

After calibrating the model for the station with the actual data the next step is checking whether the model is able to reproduce the actual data or not. This is done with two methods the first is visual inspection of the modelled value and the actual value from 1961-1990 and the other is by checking the absolute model error and variance of the modelled and the observed data.

Scenario Generations: For scenario generation the predictors H3A2a-1961-2099 and H3B2a_1961-2099 are the same type as the NCEP predictors, the difference is that the NCEP predictors used for model calibration while the H3A2a and H3B2a are used for scenario generation. The regression weights produced during the calibration process were applied to the time series outputs of the GCM model. This is based on the assumption that the predictor-predictand relationships under the current condition remain valid under future climate conditions too.

Twenty ensembles of synthetic daily time series data were produced for two of the SERS scenarios for the above future time horizons in order to increase the performance of the model. The final product of the SDSM downscaling method was then found by averaging the twenty independent GCM ensembles. The differences between the 20 ensembles do not reflect the full range of internal variability because only the stochastic component differs in each run. The deterministic component (i.e. controlled by the atmospheric circulation and moisture variables) follows the same evolution in each run because only one source of predictor (i.e. either the NCEP or HadCM3) variables exists in each case [13].

The scenario is generated for three future time horizons, from 2011-2039, 2040-2069 and 2070-2099 and for the baseline period 1961-1990 based on HadCM3A2a and HadCM3B2a.

Scenario Periods

Run	Start Date	End Date
1	1961	1990
2	1961	2010
3	2011	2040
4	2041	2070
5	2071	2099

Once the scenario data is computed in the future period, the monthly change of maximum temperature, minimum temperature from the baseline period for the station is calculated.

These changes in temperature and relative change in precipitation are superimposed up on 30 years climate records and can be used as input for other models. The change observed in one month is added to every day record of the same months in the 30 years climate data. The 30 years climate data are the actual data of maximum temperature and minimum temperature of the station used for statistical downscaling model.

RESULTS

The climate scenario for the future period was developed from statistical downscaling using the GCM (HadCM3) predictor variables for the two emission scenarios for 100 years, based on the ensemble of 20 models.

Analysis was based on three 30-year periods centred on the 2020s (2011- 2040), 2050s (2041-2070) and 2080s (2071-2099). The respective average monthly change from the baseline period for both A2 and B2 scenarios were calculated for maximum temperature and minimum temperature.

Maximum Temperature: The monthly mean maximum temperature in the baseline period (1961- 1990) and downscaled for A2 and B2 scenarios (2011-2040), (2041-2070) and (2071-2099) for Musrat station in Libya are shown in Figures 3 and 4.

The downscaling of maximum temperature in the future period (2011- 2099) for HadCM3A2a and HadCM3B2a scenarios shows an increasing trend in all future time horizons.

The average annual maximum temperature is predicted to increase by 0.7°C and 1.3°C by the 2020s (2011-2040) under the A2 and B2 scenarios, respectively. By the 2050s (2041-2070) the increase is predicted to be0.8°C under the both A2 and B2 scenarios. By the 2080s (2071-2099) the average annual maximum temperature is predicted to increase by2.6.°C and 0.1°C under A2 and B2 scenarios, respectively.

The projected maximum temperature in 2011-2040 and 2041-2070 (Figures 3) indicates that the highest rise in maximum temperature will be between 1°C to 1.9°C in March, June and July for the HadCM3A2a scenario and the lowest rise will be between -0.6 to 0.4°C in May and November.

By 2071-2099 (Fig. 3), there will be a greater increase in the maximum temperature, reaching 4.3°C under the HadCM3A2a scenario in June, July; again, a smaller increase is predicted in the months January, May and November, it will be between 1.7°C and 2.1 for the HadCM3A2a.

Figure 4 indicates that the highest rise months in maximum temperature for the HadCM3B2a scenario will reaching 2.5°C and 2.4°C in July and March by 2011-2040 and it will be decreasing to 0.9°C and 0.1°C By 2071-2099.

Generally, the data suggest that the mean monthly maximum temperature will increase in the future period. The change in maximum temperature from the baseline period is higher in the dry months than the wet months under both scenarios. As expected, the HadCM3A2a scenario predicts greater increase than the HadCM3B2a scenario.

The HadCM3A2a scenario represents a medium high scenario based on a greater increase in atmospheric CO^2 concentration than is used in the HadCM3B2 scenario.

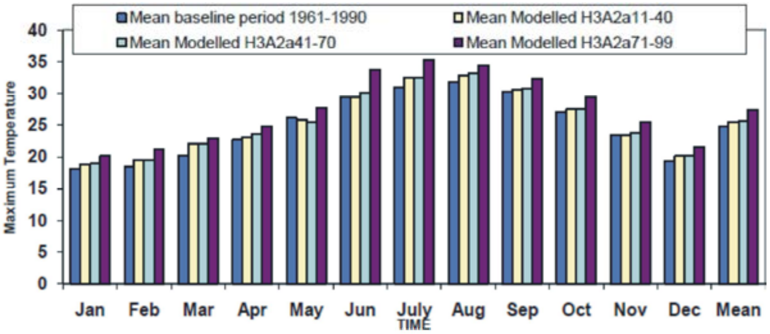

Fig. 3: Downscaled monthly mean maximum temperature for the baseline period (1961-1990) with HadCM3A2a scenario for Musrat station in Libya (1961-2099)

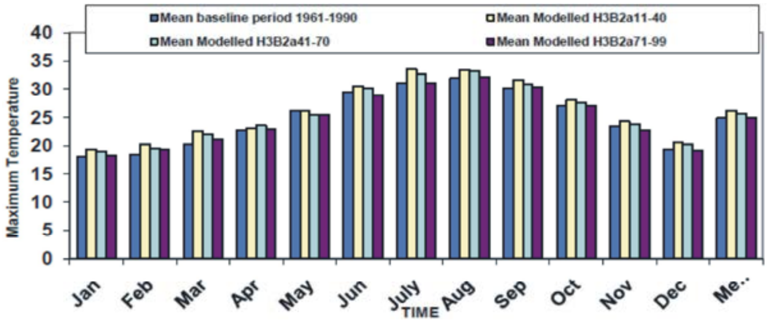

Fig. 4: Downscaled monthly mean maximum temperature for the baseline period (1961-1990) with HadCM3B2a scenario for Musrat station in Libya

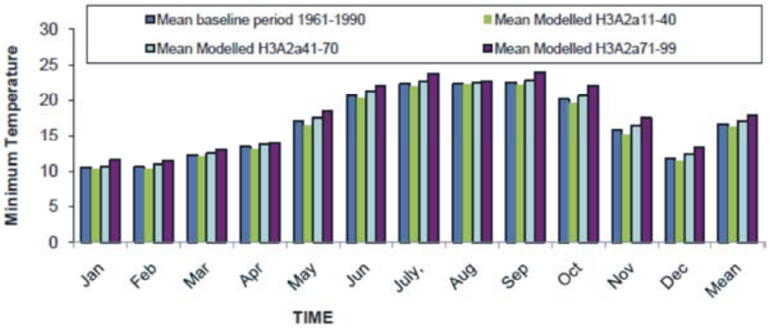

Fig. 5: Downscaled monthly mean minimum temperature for the baseline period (1961-1990) with HadCM3A2a scenario for Musrat station in Libya (1961-2099)

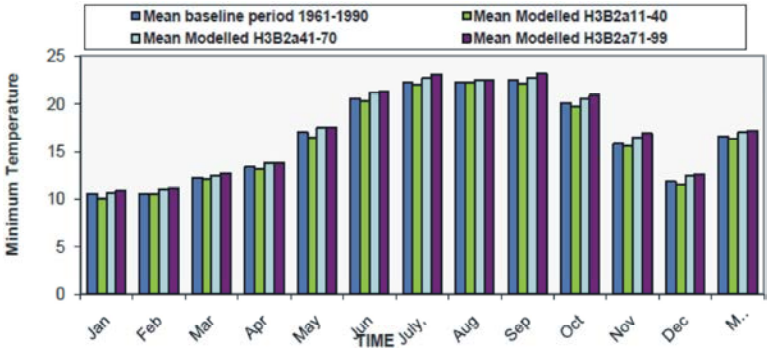

Fig. 6: Downscaled monthly mean minimum temperature for the baseline period (1961-1990) with HadCM3B2a scenario for Musrat station in Libya

Minimum Temperature: Like the maximum temperature, the minimum temperature in the baseline period (1961-1990) and the downscaled monthly mean minimum temperature with HadCM3A2a and HadCM3B2a scenarios (2011-2040), (2041-2070) and (2071-2099) for Musrat station in Libya, also shows an increasing trend in (2041-2070) and (2071-2099) for both HadCM3A2a and HadCM3B2a (Figure5 and 6).

Figures 5 and 6 indicate that the average increase in minimum temperature is 0.4°C by 2050s (2041-2070) for both HadCM3A2a and HadCM3B2a.

Figures 5 and 6 indicate that the average increase in minimum temperature in 2070s (2071-2099), is 1.2°C, in 2040s (2041-2070) for HadCM3A2a and 0.6°C for HadCM3B2a scenarios.

It is clear that in the future period (2011-2099) there will be an increasing trend in minimum temperature for both HadCM3A2a and HadCM3B2a scenarios. In addition, the increment for A2 scenario is greater than B2 scenario because A2 scenario represents a medium high scenario, which produces more CO^2 concentration than the medium low B2 scenario.

Figures 5 and 6 compares the average monthly increase of minimum temperature of A2 and B2 scenarios in individual periods 2011-2040, 2041-2070 and 2071-2099.

It indicates that there will be an increasing trend in most months for both A2 and B2 scenario in 2041-2070 and 2071-2099, but it also indicates that the minimum temperature trend in the future time horizons varies from month to month, for all periods and both scenarios.

The projected temperature in 2041-2070 indicates that the highest rise of minimum temperature will be 0.6°C for the both HadCM3A2a and HadCM3B2a scenarios in June, November and December.

The lowest increase will be 0.2°C in January and March for both HadCM3A2a and HadCM3B2a scenarios.

In 2071-2099 there will be a greater increase in the minimum temperature, 1.7°C and 1.1°C for both HadCM3A2a and HadCM3B2a scenarios from July, October and November. The lowest increase will be 0.4°C and 0.2°C for both the HadCM3A2a and HadCM3B2a scenarios in August.

Generally, the results show that the average annual and monthly minimum temperature trend in the future period will increased as compared to the baseline period for both HadCM3A2a and adCM3B2a scenarios in both dry season and wet season. However, this increase is higher in dry months than wet months for all future time horizons and for both HadCM3A2a and HadCM3B2a scenarios.

DISCUSSION

This study attempted to make some predicitions about future climate trends by statistical downscaling of GCM output. The method worked well for maximum and minimum temperature, both of which produced good agreement between validation datasets. Unconditional processes like temperature are not regulated by other intermediate processes. In addition, as indicated in the SDSM manual [12], local temperatures are largely determined by regional forcing.

The future change from the baseline period for all scenarios for the three future time horizons indicates that increase in maximum temperature is less than the increase in minimum temperature. The projected temperature trends for all future time horizons are within the range projected by IPCC which indicate that the maximum temperature will rise up to 9°C for North Africa (Mediterranean coast) to wards the end of this Century. Climate change scenarios for Africa, based on the results from several GCM studies using data collated by the IPCC, indicate future warming across Africa with ranges from 2°C (low scenario) to 5°C (high scenario) by 2100. Overall, the results of this study agree with IPCC (2008) results for temperature changes for two future periods in the next 100 years, centred on the 2040s and 2080s. They predict between +0.5°C to +1.4°C by the 2040s and between +1.3°C to + 4.5° C by the 2080s for A2a scenarios; and between +0.5°C to +1.7°C by the 2040s and between +0.9°C to +3.4°C by the 2080s for B2a scenarios.

The temperature predictions from this study are also in agreement with El Kenawy *et al.* [14], who found strong evidence of a significant warming trend in annual minimum temperature in Libya (0.23°C), resulting in an increase in the mean surface temperature.

Generally, it is possible to conclude that the statistical downscaling method is able to simulate maximum temperature and minimum temperatures for the purpose of future predictions for the study area.

Recommendations:

- The GCM outputs, the emission scenarios and the downscaling methods used for this study have certain level of uncertainty. Therefore further studies should reduce the uncertainty by the use of different GCM outputs, downscaling methods and emission scenarios. The use of several general circulation models for climate change studies able to get the better result for future climate change in Libya.

- Further studies should consider other several climatic stations data in Libya. Besides, this study can be extended by considering change in other climate variables in addition to the change in temperature.
- Improving natural recourse management efficiency should be a priority of Libyan government. It needs to prepare a national plan for adaptation to climate change.

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