Future Changes in Maximum Temperature Events Using the Statistical Downscaling Model (SDSM) in Kufra Area–Libya

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Abstract:

All the IPCC's five reports between 1990 and 2013 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. The study describes the application of statistical downscaling method (SDSM) to downscale maximum temperature data. In order to explore the SDSM method, the Kufra station in Libya has been selected as a study site to test the methodology for maximum temperature. The study included calibration and validate with large-scale atmospheric variables encompassing NCEP reanalysis data, the future estimation due to a climate scenario, which are HadCM3 A2 and HadCM3 B2. Results of downscaling show that during the calibration and validation stage, the SDSM model can be well acceptable regard its performance in the downscaling of daily maximum temperature.

Trend analysis in the study area showed an increase in average annual and monthly maximum temperature, compared to the baseline period for both HadCM3A2a and HadCM3B2a scenarios in both the dry and wet seasons. The average annual maximum temperature in Kufra area is predicted to increase by 1.3°C and 1.4°C by the 2020s (2011-2040) under the A2 and B2 scenarios respectively. By the 2050s (2041-2070) the increase is predicted to be 1.4°C, 1.7°C under the both A2 and B2 scenarios. By the 2080s, (2071-2099) the average annual maximum

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temperature is predicted to increase by 1.9 °C and 1.4°C under A2 and B2.

However, 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 affect water availability.

Keywords:

SDSM Statistical downscaling model, **IPCC** Intergovernmental Panel on Climate Change, **GCM** General Circulation model, **SERS** Special Report on the Emission Scenarios, **HadCM3** Hadley Climate Model version.

Introduction:

Climate change is one of the most important issues of the twenty-first century; increasing extremes of temperature, (McMichael et al., 2003). There is much discussion in the scientific literature and concern in the wider community about climate change, 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 (e.g., Jones et al. 2003; Arnell, N. W.2004; IPCC.2001; IPCC; **2008**) 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 economic system.

In order to best assess the expected climate change estimates on small (regional and local) , climate variables and climate change scenarios must be developed on a regional or even site-specific scale , (Wilby et al, 2001). To provide these values, projections of climate variables must be ‘downscaling’ from the GCM results, utilizing either dynamical or statistical methods (IPCC, 2007).

Downscaling can be accomplished by using either a Regional Climate Model (RCM), or a statistical technique. Statistical approaches are preferred when time and computer power are limited.

This study utilized the Statistical Downscaling Model (SDSM), developed by Wilby, Dawson and Barrow (2001). Libya is one of the driest countries in the world with significant changes recorded in temperature. In this study, the Statistical Downscaling Models (SDSM) of maximum daily temperature for Al Kufra station in Libya is predictedbased on the IPCC Scenarios A2 (Medium–High Emission scenario) and B2 (Medium–Low Emission scenario), for three time windows: 2011-2040, 2041-2070 and 2071-2099. HadAM3 model was used to examine the contributions of global mean and regional gradients change to simulated future maximum temperature change over Kufra area.
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 (1961-1990) of maximum daily temperature of Kufra station in Libya were used.

Problem Definition:

Climate change is a consequence of changing in climate on environment over the worldwide. The increase in developmental activities and Greenhouse Gases (GHGS) put a strain on environment, resulting in increased use of fuel resources; the subject of global warming has initiated this investigation concerning temporal changes of extreme temperatures in Europe and North of Africa.

Carbon dioxide has increased by 31 percent, methane by 151 percent and nitrous oxide by 17 percent (Prentice et al., 2001). The continuing of this greenhouse gas emissions phenomena at this rate, will lead to further warming and unexpected changes in the global climate system in the future (Solomon et al., 2007).
Obviously, climate change variables developed by IPCC are the most useful data to comprehend the climatic condition whether it is at global level or national level (Mearns et al., 2001). Projection of future climate trend will be highly essential for the environmental

planning and management. Changes in climate conditions may promote the events of draught or flood extremes (IPCC, 2008). Therefore, the investigation on the maximum temperature impacts on the present and future is highly demanded. On the other hand, GCMs are the currently most reliable tools to assess climate change at coarse scale but GCMs output do not meet the needed resolution to assess the climate change at regional or local scales. The grid-boxes used by GCMs are too coarse (Wilby et al., 2004). Then, GCMs cannot present the local weather and microclimate processes.

Objective of the Study:

The study first aims, to implement a spatially Statistical Downscaling Model (SDSM) of maximum daily temperature for Al Kufra station in Libya, based on 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 daily temperature for Al Kufra station in Libya.

Specific objectives of this study are:

- To analysis modelled NCEP/ (1961-2001) of maximum air temperature data at Al Kufra.
- To compare the HadCM3 output of maximum air temperature with observed trends from the weather station records.
- To determine the future trends of maximum air temperature up to 2099 for Al Kufrastation in Libya.

Study Area:

Libya is located in the north of Africa; Al Kufraarea is located in the South west of Libya between 1002479.43 to 152545.4 E longitudes and 3128079.18 to 2191542.3 N latitude as shows in figure (1).

The climate is generally described as arid, with hot and dry summers and moderate winters in the Al Kufra area. The mean annual maximum temperatures is 31°C, the mean annual minimum temperature is 17°C, (1971-2000).

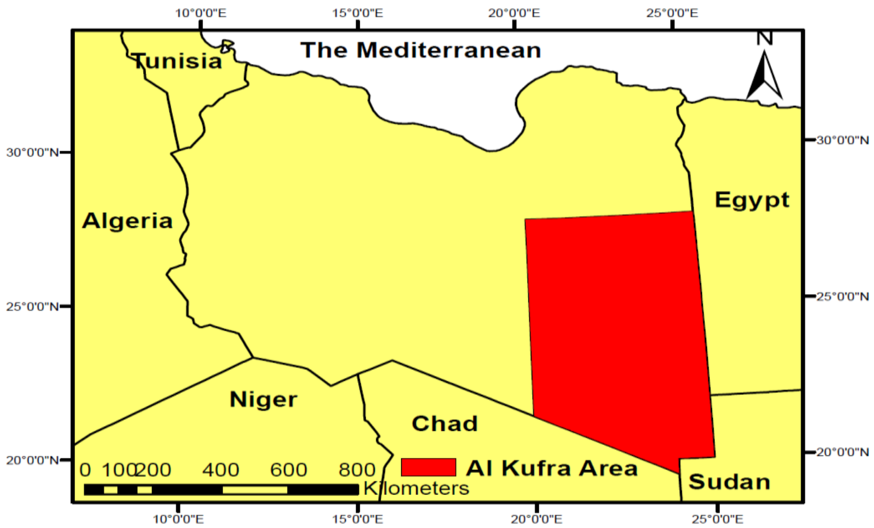

Figure (1) Location of the AL Kufra area in Libya

Data:

Daily maximum temperature of Al Kufra station in Libya for thirty years (1961-1990) were used to parameterise the downscaling model for the study area. Environmental Prediction (NCEP) products were interpolated to the CGCM2 grid over the entire African continent are. Both the GCM variables and the NCEP data sets were made available for the grid-boxes illustrated in Figure (2) illustrates the NCEP grid data for Africa.NCEP-1961-2001 It contains all the observed predictors data produced from NCEP/NCAR. Since there is a difference in the resolution in grid cells of NCEP and HadCM3, all the 41 years of daily-observed predictor data were interpolated to the same grid as HadCM3 and then the data were normalized, the horizontal grid resolution in NCEP atmospheric predictors is 2.5°, 2.5°. The 26-predictor variables are produced by state-of-art assimilation of all available observed weather data into a global climate-forecasting model that produces interpolated grid output of many weather variables (Saha et al., 2010).

The projected GCM output for both the CGCM2 and HadCM3 were used.H3A2a-1961-2099It contains 139 years of daily GCM predictor data assuming a characteristic of scenarios with higher rates of GHG emissions in combination with higher sulphate and other aerosol emissions. H3A2a was normalised over the 1961-1990 period.

H3B2a-1961-2099It contains 139 years of daily GCM predictor data assuming a characteristic of scenarios with higher rates of GHG emissions in combination with lower rate of sulphate and other aerosol emissions. H3B2a data was normalised over the 1961-1990 period. These predictor sets are available for three future tri-decadal periods; the 2020s (2011-2040), the 2050s (2041-2070), and the 2080s (2071-2099).

Therefore, Latitude/longitude of the study area and the grid box provides a zip file contains three directories: NCEP-1961-2001, H3A2a-1961-2099 and H3B2a-1961-2099.

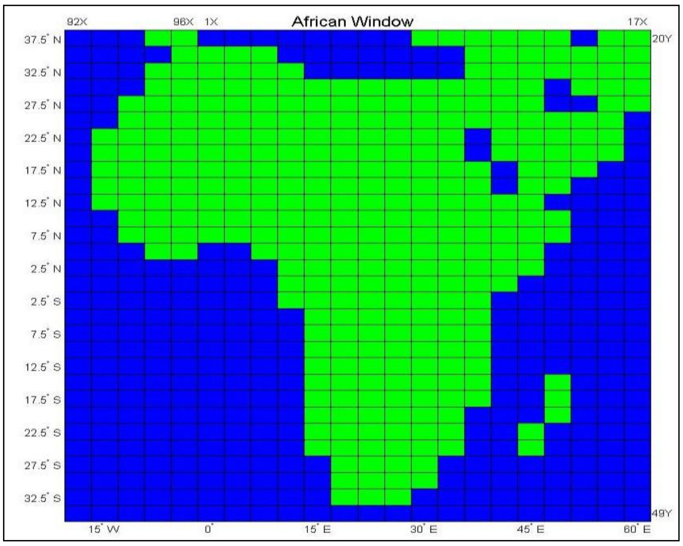

Figure (2) Large Scale Predictor NCEP Re-Analysis Data for Africa
Source: www.cics.uvic.ca/scenarios/index.cgi

Methodology:

Downscaling is a technique of changing in climate data resolution from a coarse resolution into a fine resolution. It can be developed for an area and even a point.

SDSM is a (windows) based decision support tool for regional and local scale climate change impacts assessments.

The methodology used in this study is fully described in the SDSM 'User's Manual', by Wilby Dawson and Dawson (2007).The version 4.2.9 of SDSM Figure (3) was used in this research. The software involves of several tasks as follows: quality control, data transformation; predictor variable screening; model calibration; weather generation; statistical analyses; graphing model output; and scenario generation.

The aim is to assess the suitability of the HadCM3 climate scenario to simulate climate variables in the study area against observed climate data, in order to guide their use in climate change projections. IPCC (2001; 2008) state that coupled models provide credible simulations of the present climate. This approach involves comparing GCM simulations, that represent present-day conditions (baseline climate period) to observed climate values in order to check the validity of the GCMs in Libya and in the Al Kufra study area specifically, for the baseline period (1961 to 1990).The IPCC recommends 1961-1990 as climatological baseline period in impact assessment, the HadCM3 model was employed for both A2 (Medium-High Emissions) and B2 (Medium-Low Emission) Scenarios. HadCM3 is widely applied in many climate change impact studies; see for example Ekstrom, et al. (2005), Lucio (2004), Shenglian et al. (2002) and Hulme et al. (1999).

A2 scenario (Medium-High Emissions scenario) is a scenario with higher rates of greenhouse gas emissions in combination with higher sulphate and other aerosol emissions. It represents a differentiated world and describes the world in a various economic regions in which the income gap between developed and developing countries is not narrow.

B2 scenario (Medium-Low Emissions scenario) is a lower rate of emissions that assumes the world is more committed to solving global and local environmental (IPCC, 2007).

The predictor variables selected for maximum temperature for each downscaling process conducted in this study are - Surface meridional velocity (ncepp__vaf.dat),Surface divergence (ncepp_zhaf.dat), 850 hPa meridional velocity (ncepp8_vaf.dat) and Mean temperature at 2m (nceptempaf.dat)

Figure (3) illustrates the SDSM, which has been developed by Wilby and Dawson, 2007.

HadCM3 Model is used for the GCM downscaling, which is a coupled oceanic - atmospheric general circulation model. Wilby and Dawson (2007).The horizontal resolution of atmospheric component is 2.5 by 3.75 degrees while the oceanic component's resolution is 1.25 by 1.25. The simulation of HadCM3 assumes the year length in 360 – day calendar which 30 days per month. The model was developed in 1999 and was the first coupled atmosphere-ocean, which did not require flux adjustments (IPCC, 2008). HadCM3 was used extensively in IPCC through the Third and Fourth Assessments. It also has the capability to capture the time-dependent fingerprint of historical climate change in response to natural and anthropogenic forcing (Stott et al., 2000) which has made it a particularly useful tool in studies concerning the detection and attribution of past climate changes.

All GCMs provide a version of the future, based on which emission scenario and time frame, in this study, the SRES A2 and B2 emission scenario were used for three future tri-decadal periods; the 2020s (2011-2040), the 2050s (2041-2070), and the 2080s (2071-2099).

Results:

The output generated by the HadCM3 GCM model has projected an increase in maximum temperature for Al Kufra area, Results were generated by month, season and annually for maximum temperature.

- **Comparison for the baseline period of GCM with observations**

This approach involves comparing GCM simulations that represent present-day conditions (baseline climate period) to observed climate values in order to check the validity of the GCMs in Al Kufra area.

The IPCC recommends 1961-1990 as climatological baseline period in impact assessment.

Figure (4) shows the observed and modelled result of monthly mean of daily near surface air maximum temperature in the for Al Kufra station (1976-1990).

As indicated in Figures (5&6) the downscaling result of maximum temperature with HadCM3A2a and HadCM3B2a scenarios output will not show much difference in the actual and modelled result. The model error, which is the difference of the observed and the simulated maximum temperature, indicates that the maximum absolute error is between (0°C to-0.4°C) for all the months.

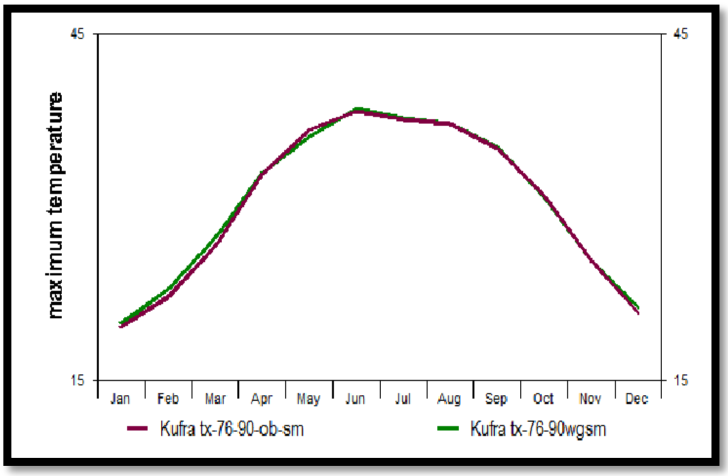

Figure (4): Comparison of observed vs. downscaled simulated maximumtemperature for Al Kufra station (1976-1990)

Application of downscaled scenarios for future periods:

The future climate was projected using SDSM as presented in methodology; the climate scenario for the future period was developed from statistical downscaling using the GCM (HadCM3) predictor variables for the two emission scenarios, based on the ensemble of 20 models.

Analysis was based on three 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. The output generated by the HadCM3 GCM model for the Al Kufra station has shown in Figures (5&6).

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

The average annual maximum temperature is predicted to increase by 1.3°C by the 2020s (2011-2040) under A2 scenarios.
By the 2050s (2041-2070) the increase is predicted to be 1.4°C under the A2 scenarios. By the 2080s, (2071-2099) the average

annual maximum temperature is predicted to increase by 1.9°C under A2 scenarios.

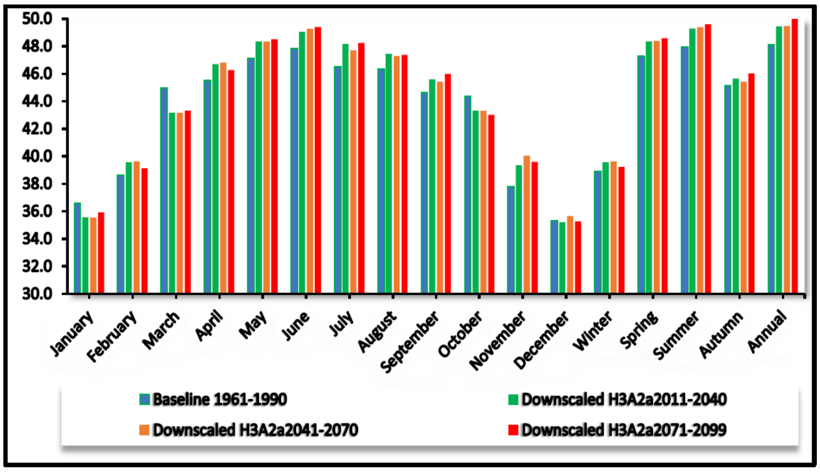

Figure (5): Downscaled monthly mean maximum temperature for thebaseline period (1961-1990) with HadCM3A2a scenario for Al Kufra station (1961-2099).

Figure (6) shows the downscaling of maximum temperature in the future period (2011-2099) for HadCM3B2a scenarios in general shows an increasing trend in all future time horizons.

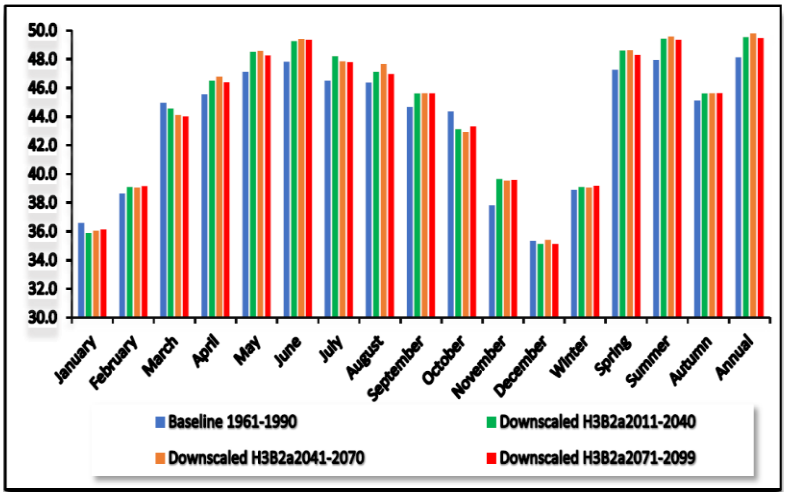

Figure (6): Downscaled monthly mean maximum temperature for thebaseline period (1961-1990) with HadCM3B2a scenario for Al Kufra station (1961-2099).

The average annual maximum temperature is predicted to increase by 1.4°C by the 2020s (2011-2040) under B2 scenarios. By the 2050s (2041-2070) the increase is predicted to be 1.7°C under the B2 scenarios. By the 2080s, (2071-2099) the average annual maximum temperature is predicted to increase by 1.4°C under B2 scenarios.

Generally, the data suggest that the mean monthly maximum temperaturewill increase in the future period under both A2 and B2 scenarios for the periods 2011-2040, 2041-2070 and 2071-2099.

Change from the baseline period is high in dry months for all periods andboth scenarios, while wet months showed less increase than dry months, and this has important implications for inthe Al Kufra region.

It is clear that in the future period (2011-2099) there will be an increasing trend in maximum temperature for both HadCM3A2a and HadCM3B2a scenarios.

In addition, the increment for A2 scenario is greater than B2 scenarios because A2 scenarios represents a medium high scenario, which produces more CO_2 concentration than the medium low B2 scenario.

Discussion:

The results of the study is in agreement with the findings of all the IPCC's five reports, which indicate that the maximum temperature will rise for North Africa towards the end of this Century. Trend analyses demonstrate a warming trend in the maximum surfacetemperature,however, this trend is more pronounced especially in the summer.

Alsothe results of the study are similar to the study conducted by the researcher in the areas of Zliten, which shows that there is a clear trend towards warming in Libya and this corresponds to the results of the the IPCC's five reportsof the North African region.

More research is needed for a clearer understanding of the future changes in the climate over all Libyan climatic stations. For example, ensemble projections of the most recent and high resolution GCMs and/or RCMs can be used to explore the future changes in climate extreme events and to understand the uncertainties related to these climate models.

التغييرات المستقبلية في درجة الحرارة العظمى بمنطقة الكفرة – ليبيا باستخدام تقنية (SDSM)

د. عبد السلام أحمد محمد إبراهيم الوحيشي*

إن تغير المناخ هو أحد أهم قضايا القرن الحادي والعشرين؛ (ماكميشل إت آل. 2003)، أن حجم الاحترار فى القرن 21 من المرجح أن يكون أكبر من أي قرن فالعديد من الدراسات (مثل جونز وآخرون 2003؛ أرنيل، N. W. 2004؛ الهيئة الحكومية الدولية المعنية بتغير المناخ، 2001؛ الهيئة الحكومية الدولية المعنية بتغير المناخ، 2008) يشير إلى أن متوسط درجة الحرارة السطحية السنوية قد ازداد (0.3–0.6) درجة مئوية منذ أواخر القرن 19، ومن المتوقع أن تزيد بنسبة (1–3.5) درجة مئوية على مدى السنوات ال 100 المقبلة. هذه فإن التغيرات في المناخ سيكون لها تأثير كبير في البيئة الإيكولوجية والاجتماعية والاقتصادية ومن أجل تقييم أفضل لتغير المناخ المتوقع والتقديرات المتعلقة بالمتغيرات الصغيرة (الإقليمية والمحلية)، يجب وضع سيناريوهات على نطاق إقليمي أو حتى موقع معين، (ويلبي إت آل، 2001).

تهدف الدراسة لإستخدام نموذج SDSM لدرجة الحرارة اليومية العظمى لمحطة الكفرة في ليبيا لتحديد الاتجاهات المستقبلية لدرجة الحرارة العظمى حتى سنة 2099 ,واستخدمت سيناريوهات نموذج HadCM3 لكل من A2 وB2 لثلاثة فترات مستقبلية (2011–2040)،(2041–2070)،(2071–2099).

* جامعة الزيتونه - ترهونه

والنتائج التي تم الحصول عليها من نموذج HadCM3 مقارنة بخط الأساس 1961–1990 تشير إلى أن الحد الأقصى للخطأ بين(0 درجة مئوية إلى –0.4 درجة مئوية) وفق السيناريوهات الاتية:–

A2(سيناريو الانبعاثات متوسطة وعالية) الحد من الحد الأقصى بدرجة الحرارة في الفترة المقبلة (2011 –2099) لسيناريوهات HACM3A2a يظهر العام اتجاها متزايدا فمن المتوقع أن تزيد من درجة الحرارة 1.3 درجة مئوية بحلول (2011–2040) وبحلول (2041–2070) تصل الزيادة الى 1.4 درجة مئوية وبحلول (2071–2099) من المتوقع أن يزيد متوسط درجة الحرارة العظمى بمقدار 1.9 درجة مئوية.

B2 سيناريو (سيناريو منخفض ومتوسط) هناك اتجاها عاما لإرتفاع درجة الحرارة العظمى 1.4 لتصل درجة مئوية (2011–2040) و 1.6 درجة مئوية للفترة (2041–2070) و1.7 درجة مئوية (2071–2099) عموما، نتائج الدراسة تتفق مع نتائج جميع التقارير الخمسة للفريق الحكومي الدولي المعني بتغير المناخ فكلها تشير إلى أن درجة الحرارة العظمى سوف ترتفع في شمال أفريقيا حتى نهاية هذا القرن وتظهر التحليلات اتجاه عام للإحترار ويكون هذا الاتجاه أكثر وضوحا خاصة في فصل الصيف.

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