
Volume 63, Issues 2–3, September 2008
ISSN 0921-8181
ELSEVIER
GLOBAL and PLANETARY CHANGE
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Special Issue
Mediterranean Climate: Trends, Variability and Change
P. Lionello, S. Planton and X. Rodó
(Guest Editors)

Global and Planetary Change 63 (2008) 163–170

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Climatic trends to extremes employing regional modeling and statistical interpretation over the E. Mediterranean

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ARTICLE INFO

Article history:
Received 1 October 2006
Accepted 20 March 2008
Available online 3 April 2008

Keywords:
extreme rainfall
extreme temperature
E. Mediterranean
climate trends
rainfall downscaling

ABSTRACT

Results of regional climate modeling performed at the International Centre for Theoretical Physics, Trieste, Italy, are analyzed for the E. Mediterranean region. It is found that the average temperature over the Mediterranean area has increased by 1.5–4 °C in the last 100 yr. The temperature in the years 2071–2100 according to the A2 and B2 scenarios are predicted to increase by about 4 °C and 6 °C respectively over Northern Israel in comparison with the control run for 1961–1990.

The precipitation above most of the Mediterranean shows a dominant negative trend in the last 50 yr. A large negative trend in the A2 scenario is found over Northern Israel, while B2 scenario shows no significant trend. There is a tendency toward extreme events. It is found that the extreme precipitation over Northern Israel shows significant increasing trends for the A2 and B2 scenarios with respect to the present climate. Also, the standard deviation of the average annual precipitation is higher in the A2 and B2 scenarios showing a trend toward both drier as well as wetter years in the future.

1. Introduction

In the last decades the awareness toward the phenomenon of the global warming has significantly increased. According to the IPCC (2007) report the averaged global temperature of the world has increased by 0.74 °C in the last 100 yr. Also, IPCC (2007) suggests an increased tendency toward extreme events of droughts on the one hand and floods on the other.

In the E. Mediterranean (EM) recent climate trends include a decrease in winter temperatures and total precipitation amounts, accompanied by increases in the rainfall over the southern part of the region (IPCC, 2001) and extreme daily rainfall (Alpert et al., 2002, Yosef et al., submitted for publication). Some of these features are apparently caused by the global warming effects due to a significant increase in the concentration of greenhouse gases (GHG) in the atmosphere. Role of teleconnections appears to be essential. The NAO index increase till the 90s explains the cooler and drier winters over the EM during the period (Ben-Gai et al., 2001; Krichak and Alpert, 2005b). The fact that the south EM was not influenced by a significant and dominant rainfall decreases over the region may be explained by positive contribution of the positive trend in occurrence of the EA/WR pattern (Krichak et al., 2002; Krichak and Alpert, 2005a). Also, increases in intensity and number of El-Nino events were found to be positively correlated to rainfall in the region (Price et al., 1998). The rainfall increase in the southern part of Israel has possibly been affected by the local land-use changes over central to south Israel (Otterman et al., 1990, Ben-Gai et al., 1993, Perlin and Alpert, 2001). Other Mediterranean climate connections to tropical systems like the Indian Monsoon, Saharan dust, etc. were also pointed out recently by Alpert et al. (2005).

The increase of extreme rainfall over Israel in spite of the decrease in rainfall totals reflects a change in the rainfall distributions. The latter is suggested to be the result of increase in tropical/mid-latitude interactions during the period. The trend has been associated with an increase in the frequency of occurrence of Red-Sea trough synoptic systems Alpert et al. (2004). It is not yet clear if the detected trend was a consequence of the global warming or was caused by natural climate variations.

The investigation was performed as a part of international research efforts under GLOWA Jordan River Project (http://www.glowa-jordan-river.de/Main/HomePage). The analysis is based on results of the Regional Climate Modeling (RCM) simulations (RCM-ICTP in the following) performed for the EU PRUDENCE project (Deque et al., 2005) at the International Centre for Theoretical Physics (ICTP) with the RegCM model (Giorgi et al., 2004a,b). Namely, the model outputs on temperature and rainfall changes are analyzed over the EM and in particular Jordan River basin for 2071–2100 compared to 1961–1990 with the aim of a better understanding of possible future climate changes in the region. The RCM runs were driven from the lateral boundaries by data from global coupled atmospheric–ocean model HadCM3, additionally downscaled with its higher-resolution (140 km) atmospheric version HadAM3H (Deque et al., 2005). The modeling data have been made available

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doi:10.1016/j.gloplacha.2008.03.003

by the ICTP for two periods (1961–1990 and 2071–2100) with the former representing current climate and the latter the future climate conditions determined in accordance with the IPCC scenarios A2 and B2 assuming more intense and less intense GHG emission regimes during the XXI century. A large-scale analysis of the modeling results has been already presented by Giorgi et al. (2004a,b).

In the current study we perform a more detailed evaluation of the data focusing on the EM region. Results of the analysis are presented and discussed in view of the recent observed temperature and precipitation trends calculated for 1948–2000 (Saaroni et al., 2003; Alpert, 2004; Ben-Gai et al., 1999) based on the National Center for Atmospheric Research National Center for Environmental Prediction (NNRP, Kalnay et al., 1996) reanalysis. In spite of the evident deficiency of this source of information (Bengtsson et al., 2004) with respect to its application in climate change studies, the earlier evaluations demonstrate a reasonable agreement between the data with the other observations available over the Mediterranean area. We also compare the modeling results with those of the Climate Research Unit (CRU) of the University of East Anglia data archives (New et al., 1999, 2000).

The importance of this research is in the necessity to evaluate the vulnerability of water resources in the Middle East; a region which experiences rising water demands along with a gradual decrease of available water. In the next section (Section 2) the summer temperatures — recent observations vs. projections trends, are compared. Section 3 does a similar comparison for main winter (DJF) rainfall. Next, extreme temperatures and rainfall projections for the end of the 21st century, are presented, (Sections 4 and 5, respectively) and followed by the Discussion and Summary sections.

2. Temperatures — summer (JJA)

Fig. 1 (from Saaroni et al., 2003) shows significant warming of summer (JJA — June, July, August) for 850 hPa temperatures over the Mediterranean. Trend values of 1.5–4 °C/100 yr, based on NNRP reanalysis for 1948–2003, cover the whole Mediterranean with two maxima over the Western Mediterranean and North Egypt. These outstanding heating trend values are about 3–4 times larger than global trends for the last 100 yr. The result may be partly affected by the changes in the observation system during the period of analysis (Bengtsson et al., 2004). The trend is in agreement however with somewhat smaller heating trend (Giorgi, 2002) based on the data archive for terrestrial regions produced by the CRU, New et al. (1999, 2000).

The near surface air temperature differences from 2071–2100 compared to 1961–1990 are based on the RCM-ICTP results for two International Panel for Climate Change (IPCC) emission scenarios A2 and B2. The A2 scenario assumes a significant increase of the GHG concentration during the XXI century whereas the B2 is based on less extreme estimates (for more detail, e.g. IPCC, 2001).

According to the RCM-ICTP data under the A2 scenario, the changes over the Eastern Mediterranean are about 3–5 °C, while for B2 scenario the differences are only about 2.5–3.5 °C (Fig. 2). It is interesting to note that the surface heating trend projections over the sea are lower than over the surrounding land, which is just the opposite case for the observed NNRP-based temperature trends from 1948. In the observations (Fig. 1) the trends farther inland are only about 0–0.8 °C/100 yr, and in some regions (Algeria, Balkan) even negative trends are seen (although in the coastal land areas higher values up to 1.6 °C/100 yr are observed). Since the warming over the Mediterranean Sea is of the same magnitude, can we conclude that the warming over land is also going to accelerate in the 21st century? Or, that the models are not doing a good job? Or maybe there are significant variations from 850 hPa to the surface? The answer is not yet clear. Additional investigations of the issue are currently in process based on results from the RCM simulations at Tel-Aviv University (Krichak et al., 2007) and will be presented separately.

3. Rainfall — winter (DJF)

According to the NNRP data observed precipitation trends over nearly the whole Mediterranean are dominantly negative during 1948–2000 (Alpert et al., 2004; Piervitali et al., 1998). The NNRP data on precipitation are based on the model estimates and are not necessarily accurate. The results are supported however by numerous observational rain gauge-based studies e. g. IPCC, 2001; Alpert et al., 2002.

The RegCM-ICTP results for 2071–2100 compared to 1961–1990 show large differences between scenarios A2 and B2 (Fig. 3). The black box in the figure is centered over Israel and the Jordan River basin. In A2, most of the Eastern Mediterranean (EM) shows rainfall reduction of about 15–75 mm for DJF, which is equivalent to drops of about 10–30%. The DJF period covers most of the annual rain in the

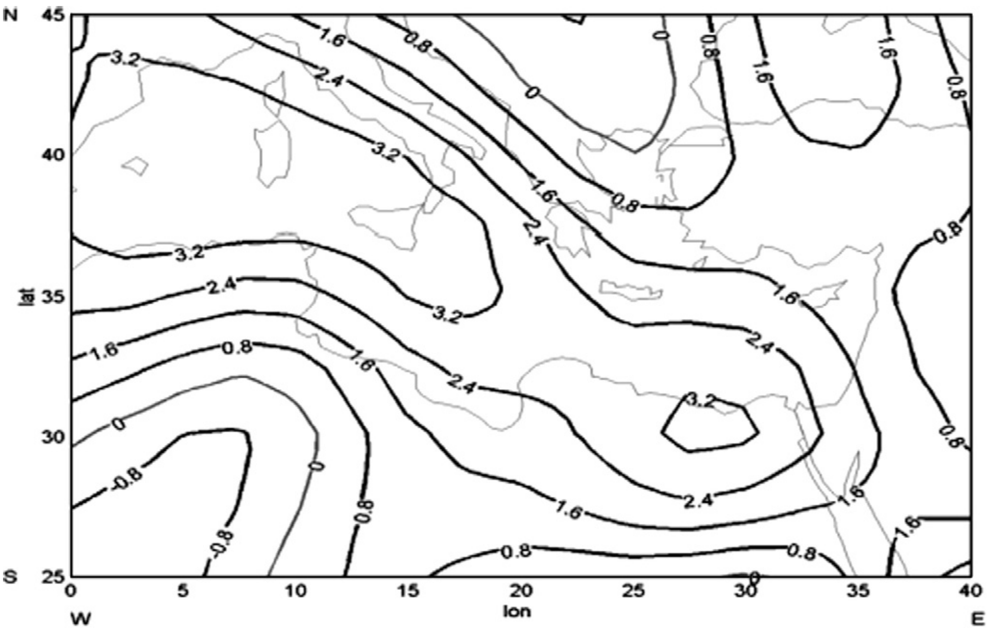

Fig. 1. Summer (JJA) trends of 850 hPa temperature (°C/100 yr) based on NNRP reanalysis for 1948–2003 (from Ziv et al., 2004), over the Mediterranean region.

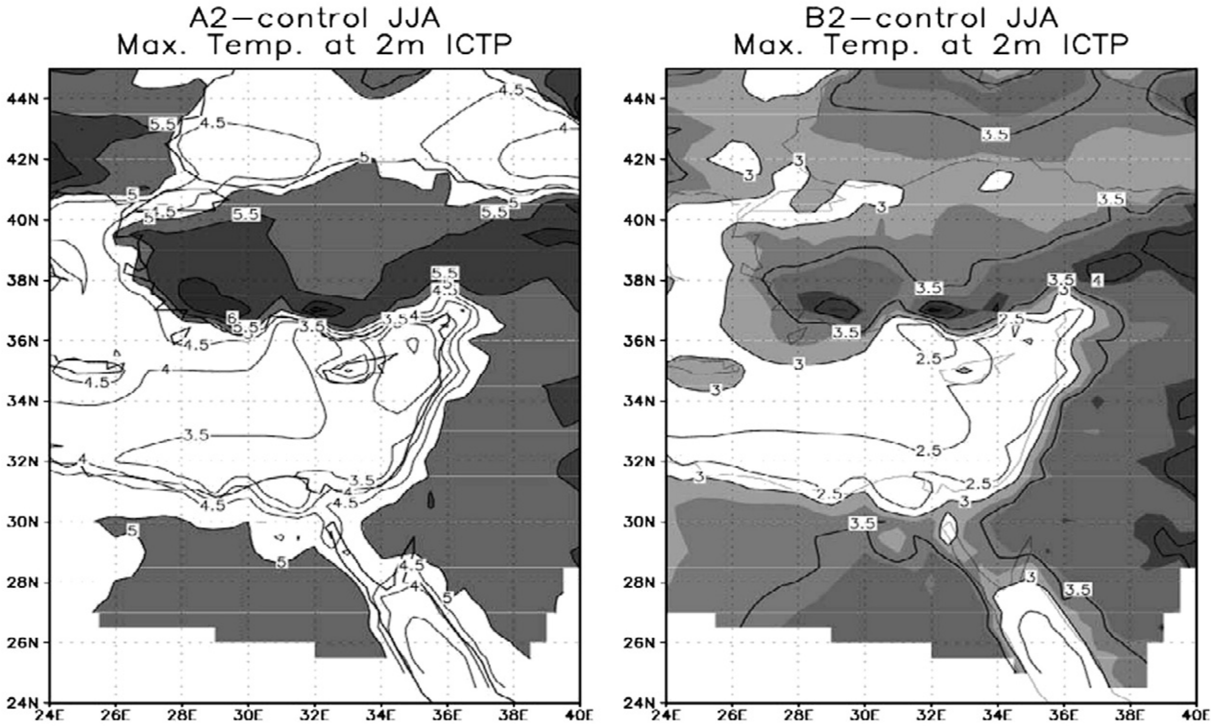

Fig. 2. The summer (JJA) predicted change in the mean maximum daily temperature at 2 m. Differences are between A2 and B2 scenarios (2071–2100) as compared to the control run (1961–1990) values over the EM, and are based on the RCM-ICTP runs.

EM, and realistically reflects the annual rainfall changes, although some changes in seasonal distribution of rainfall are predicted as discussed in Section 5. In scenario B2, however, (Fig. 3) reductions are significantly lower and are of about 0–5% in total rainfall, while over most of Turkey significant rainfall increases are noticed. The predicted rainfall changes in B2 are similar to those observed over the EM during

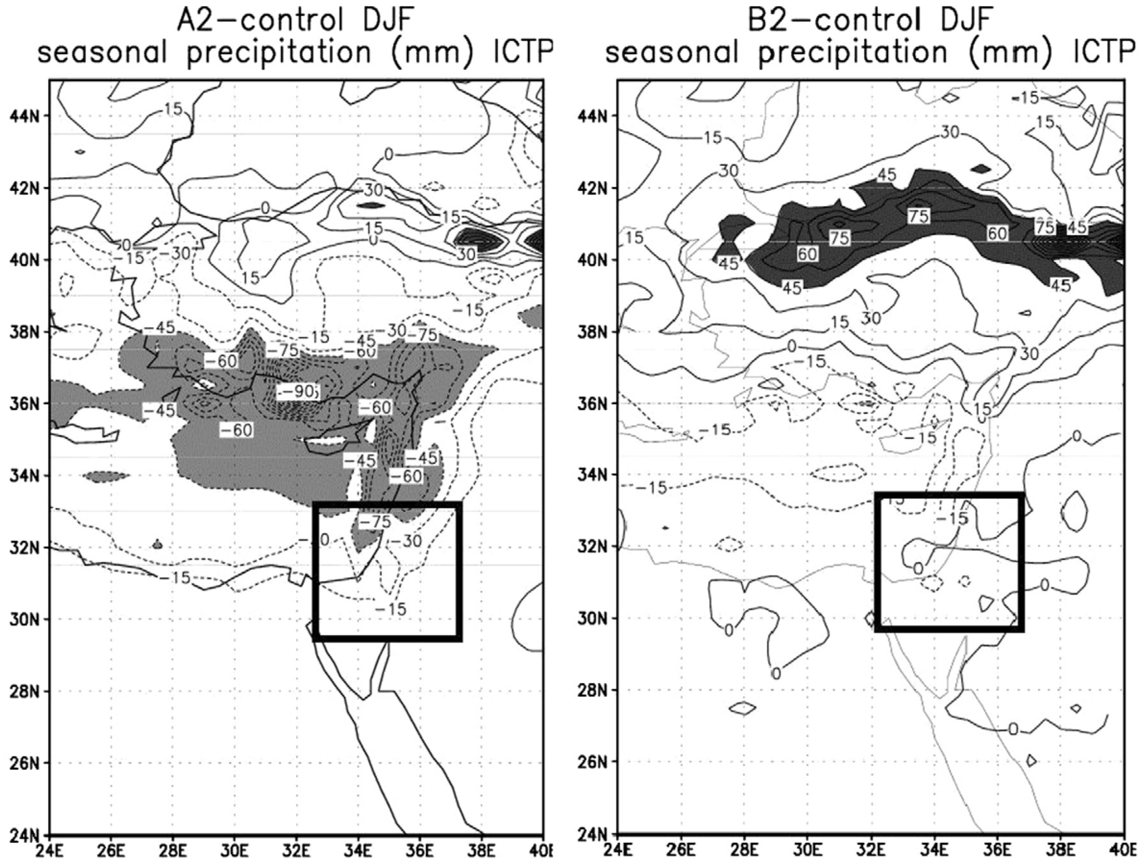

Fig. 3. As Fig. 2 but for the mean seasonal precipitation (mm) in the winter (DJF). The black box is centered over Israel and the Jordan River basin.

the recent decades (e.g., Alpert, 2004, Fig. 1.6.1; IPCC, 2001) that also show larger precipitation decreases over the NE Mediterranean and some small increases over the SE Mediterranean.

4. Extreme temperatures

Model results normally underestimate the extremes. This is a direct consequence of the model simplifications as well as the limited space resolution. Hence, to be able to apply the model results in order to realistically evaluate frequency distributions of the model, the application of correction and statistical interpretation techniques, are required. In this study we apply a statistical correction method developed by Deque (2007). In the reader's interest, a short description of the method is provided below. It is usually assumed that model biases are independent of the GHG concentration (Wilby et al., 1998). According to the correction method by Deque (2007), the cumulative-density function (cdf) and the probability density function (pdf) in the post-processed time series are assumed to be exactly the same as the cdf or pdf of the observations. In accordance with this the RCM errors in representation of meteorological parameters of different percentiles are assumed to remain unchanged in the future climate conditions as compared to the current-control run. So, a correction function is determined based on the results of comparison between the current climate model produced and the observed.

Results of application of the method are given in the following. The area on which we focus here is over N. Israel and particularly the Jordan River (JR) Upper Catchment (UCJR). Fig. 4 shows the geographic area super composed with the model grid of 50 km interval.

In the JR area (denoted by UCJR — Upper Catchment of the Jordan River) we focus on two stations, one mountainous – Har Knaan – about +934 m above mean sea level height and the other in a nearby Valley station called Kfar Blum at the elevation of about +75 m (Fig. 4). Both stations with about 850 m height separation fall within one grid box of the RCM-ICTP experiment. Next, let us illustrate how the statistical interpretation is performed for these two stations. Fig. 5a shows the centile daily maximum temperature, Tmax, distribution in the mountain station for 1961–1990 observations and the control (1961–1990) RCM-ICTP run. In addition, the same distributions for the two scenarios A2 and B2 are shown. As expected the future climates according to the A2 and B2 scenarios are significantly warmer for all centiles. However, the control run has also a warm bias. Following the Deque (2007) correction approach, this bias is removed for each centile and the same bias correction is employed to correct the results of the RCM simulations according to the A2 and B2 scenarios (Fig. 5b). Fig. 5c shows the final result for the Valley stations — Kfar Blum in the UCJR. The most extreme daily Tmax observed in this station for 1961–1990, was of about 42 °C while in scenario A2 the expected total daily maximum is expected to be of about 48 °C. At the bottom of Fig. 5b and c the distributions of the differences between the A2 and B2 scenarios and the observations are seen. According to these differences a temperature rise of about 6 °C is expected at the end of this century for A2 at both stations. A similar increase is projected for most of the centiles. In scenario B2 the temperature increases are lower and of the order of about 4 °C. Fig. 6 shows the regular Tmax distributions for all four curves for the mountain station. Interesting to note is that the most common Tmax value in the 1961–1990 observations is about 29 °C and it changes to 32.5 °C and 34°°C for the B2 and A2 scenarios, respectively. Also, the temperature variances for A2 and B2 scenarios somewhat increase. It is interesting to note that secondary peaks exist for circled values of the temperature and this seems to be the result of

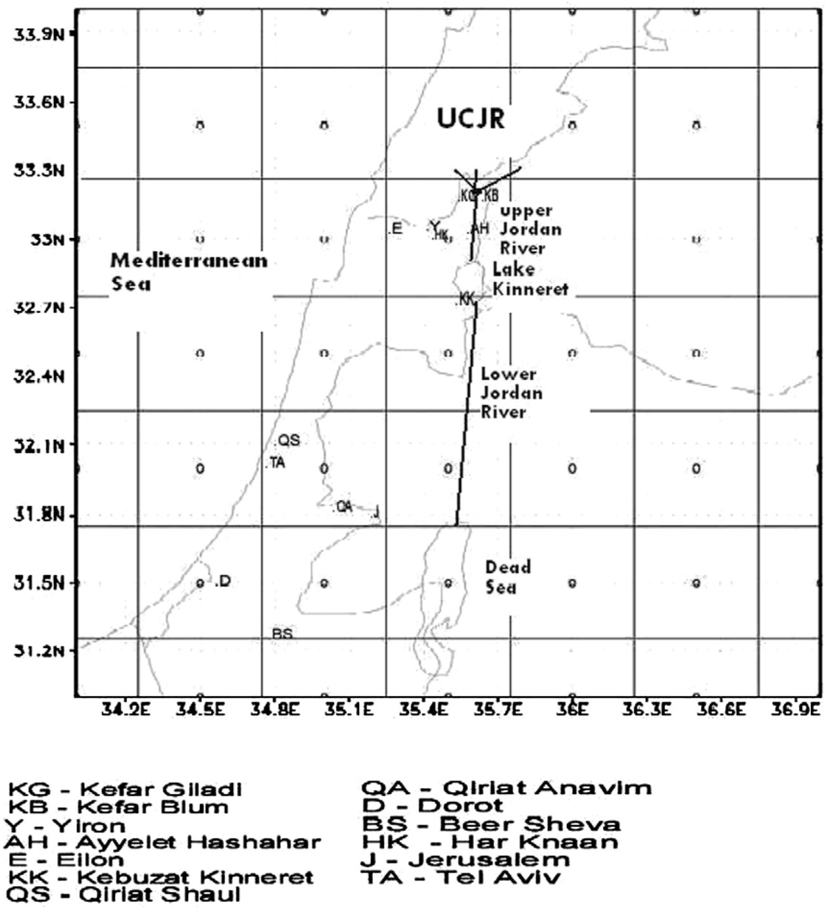

Fig. 4. Map of the SE Mediterranean focused on the location of the 12 stations in Israel used in this study. In circles the RCM model grid-points are denoted. The Upper Catchment of the Jordan River (UCJR) is indicated.

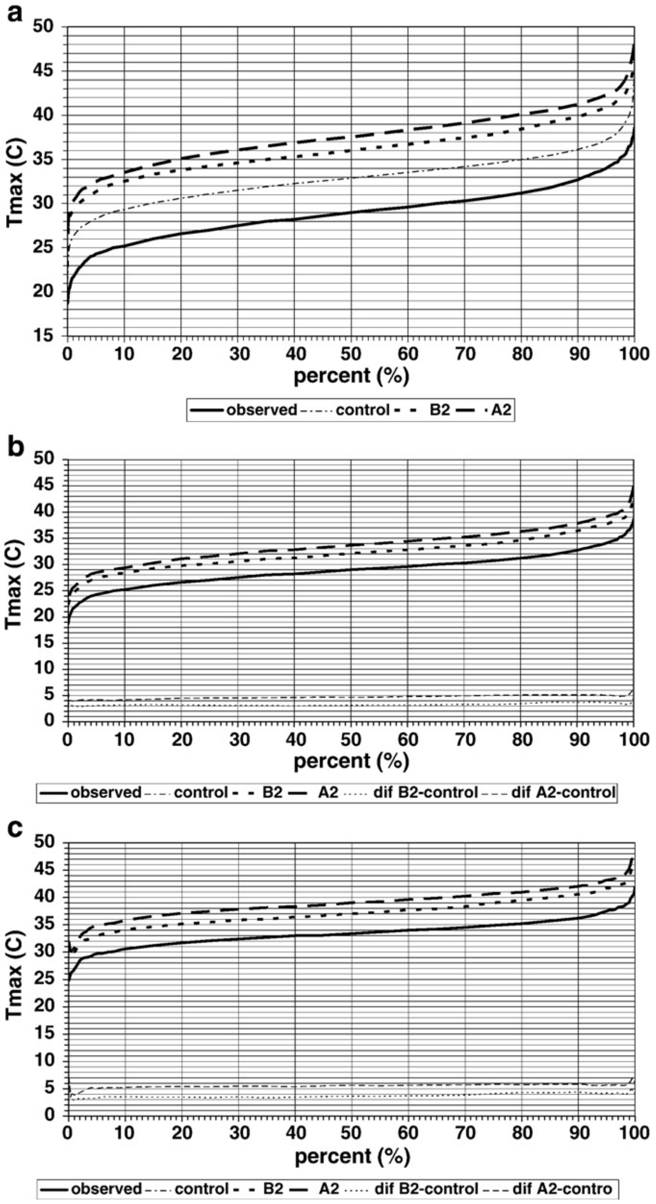

Fig. 5. a: The centile distribution of the daily Tmax (°C) in summer at the mountain station (Har Knaan, see Fig. 4 for location). The observed and control runs (1961–1990) as well as the predicted A2 and B2 (2071–2100) distributions, are shown. b: As Fig. 5a but after the bias correction following the Deque method. At the bottom, the distributions of the differences between the B2, A2 and the actual observations, are also shown. The bias corrections make the observation and the control run daily Tmax identical. Therefore, the control run line is hidden by the observed line. c: As Fig. 5b but for the valley station (Kfar Blum).

the tendency of meteorologists to circle the measured value of the temperature. Obviously, the bias-correction methodology adopted here following Deque does transfer these secondary peaks further into the other curves.

5. Extreme rainfall

Fig. 7a and b shows the centile distributions of the rainfall at the mountain station performed analogously to those for the temperature in Fig. 5a and b. Here, the daily rainfall is predicted to be lower in 2071–2100 for nearly all the centiles. However, in the few upper centiles (from about 95% and up) the tendency is just the opposite (Fig. 8a and b). In Fig. 8b the upper half-centile (99.5–100%) is zoomed in and clearly shows significant increases in the heavy rainfall daily

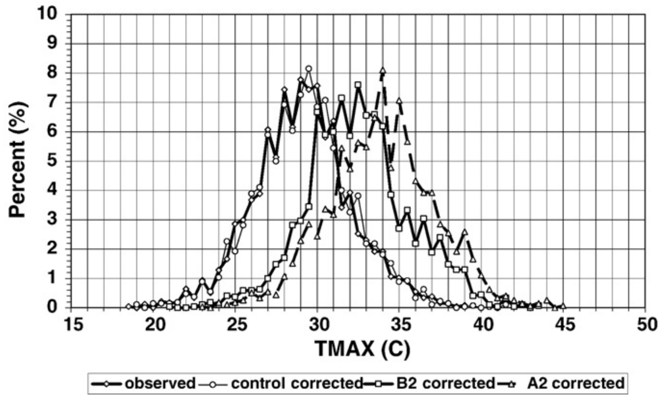

Fig. 6. The summer (JJA) Tmax distributions (in %) for the mountain station (Har Knaan) in observations, control run and corrected B2 and A2, are shown. The percentage numbers of days in half degree resolution for each Tmax are shown.

intensities. Results of similar statistical interpretation performed for twelve stations all over Israel (shown in Fig. 4) are summarized in Table 1. The table shows the 99.5% centile extreme value of the rainfall per day (mm/d) based on a period of 30 yr. The values for the B2 and A2 scenarios include the correction (Deque, 2007) based on control vs. observations (see the table caption for additional explanations). Several points may be noted. First, stations close to each other but with significant differences in their surface parameters like Har Knaan and Kfar Blum (numbers 10 and 11) in the JR basin or Jerusalem and Kiryat Anavim (numbers 3 and 4) show also significant variations in the future scenarios. Second, the more northerly mountainous

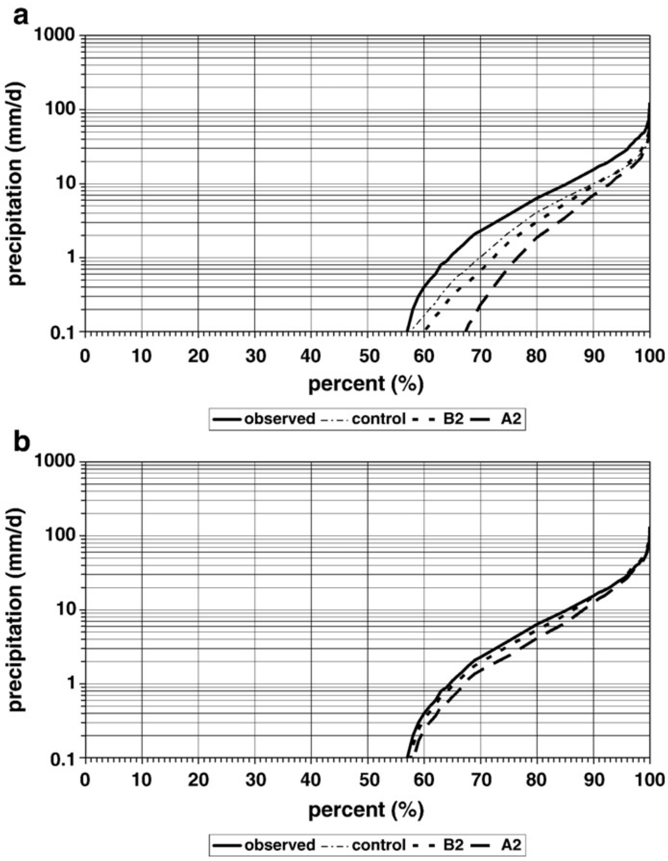

Fig. 7. a: As Fig. 5a but for the daily precipitation (mm/d) for winter (DJF) at Har Knaan. b: As Fig. 7a but after the bias corrections following the Deque method. The bias corrections make the observations and control run distribution identical. Therefore, the control line is hidden by the observation line.

stations (7, 8, 10 and 12) have generally higher frequencies of heavy rainfall under the future climate conditions. There are exceptions however (like that in the case of Kiryat Anavim — number 4) with the higher frequency in spite of its more southern location. Another point to be noted is the change of the seasonal distribution of the heavy rainfall days (Fig. 9). Fig. 9 shows, that under the global warming conditions according to scenario B2, there is a tendency for increase in the number of "heavy rainfall" days during autumn and early winter compared to the current climate. Note, for instance, 6 d in future October climate (B2) compared to zero under the current climate, or 16 compared to 7 d for December. At the same time the B2 scenario climate in the region is characterized by a reduction in the number of such days during winter (10 d to only 4 in January). The future climate conditions under the A2 emission scenario are characterized, however, by the tendency for increase in the number of heavy rain days during spring.

Fig. 10a and b summarizes the annual averages as well as standard deviations for all 12 stations in Israel for which the Deque (2007) statistical correction procedure was applied. The major finding is decreases in annual rainfall associated with increases in the standard deviations. This suggests over Israel a trend toward a more arid climate, along with a trend toward both drier as well as wetter years in the future. The result fits those of other studies predicting increases in the rainfall variability over the world, e.g. IPCC (2001). In the Mediterranean this process goes paradoxically in parallel with overall decrease of rainfall as discussed by Alpert et al. (2002) and Alpert (2004). It should be noted that the typical pattern over most regions in the world is not in this pattern but with increase (decrease) of extreme rainfall that goes along with increase (decrease) in the totals (based on IPCC, 2001). Over Israel the tendency to more extreme years can be related to the increase of the specific "Red-Sea trough" (RST) synoptic system whose frequency has doubled in the recent 50 yr (Alpert et al., 2004).

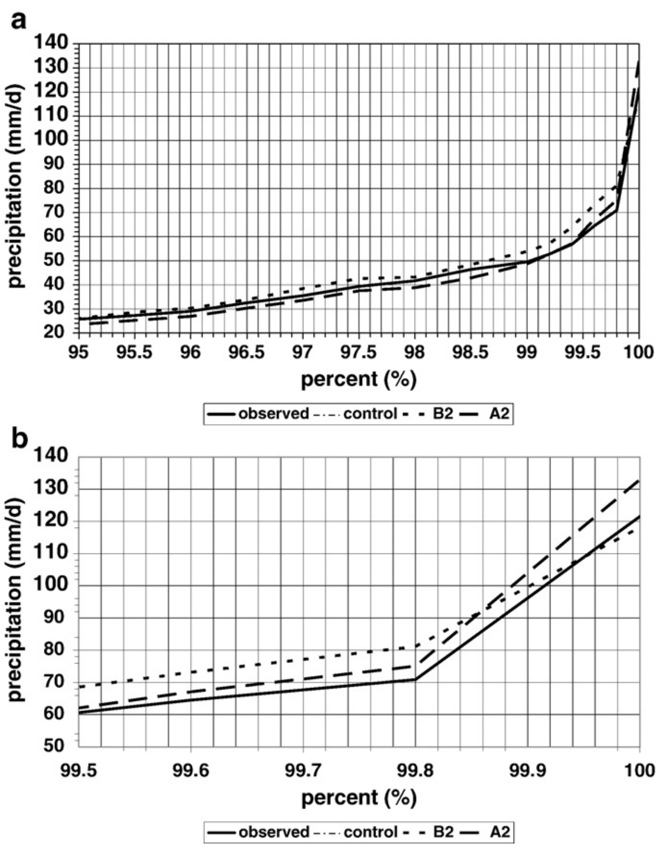

Fig. 8. a: As Fig. 7b but zooming on the extreme rainfall of the upper 95–100% centiles. b: As Fig. 8a, but zooming on the 99.5–100% centiles.

Table 1
The 99.5% centile extreme value of the rainfall per day (mm/d) based on the 30 yr period. The values are for 12 stations all over Israel from south to north where Beer-Sheva (station no. 1) is the most southern station in the semi-arid zone of the Negev desert. The values for the scenarios B2 and A2 include the factor correction based on the control run against the observations for the period 1961–1990. This factor was obtained by the ratios of the 99.5% value observed centile and the control run 99.5% centile. In parentheses the percentage-wise change for B2 and A2 (after the correction) as compared to the observations is given. At the bottom, averages for all 12 stations and for the north (stations 7–12), are denoted

No.	Station	Observation	B2	A2
		1961–1990	2071–2100	2071–2100
1	Beer-Sheva	21.3	22.5 (+5.6)	19.8 (−7.0)
2	Dorot	31.1	28.5 (−8.4)	28.1 (−9.6)
3	Jerusalem	47.5	47.5 (+0.0)	44.3 (−6.7)
4	Qiriat Anavim	54.2	53.5 (−1.3)	50.9 (−6.1)
5	Tel- Aviv	41.8	40.9 (−2.2)	37.7 (−9.8)
6	Qiriat Shaul	44.1	43.7 (−0.9)	41.9 (−5.0)
7	Eilon	50.4	56.3 (+11.7)	51.1 (+1.4)
8	Yiron	51.7	54.6 (+5.6)	50.2 (−2.9)
9	Kebuzat Kinneret	30.3	33.6 (+10.9)	30.8 (+1.7)
10	Har Knaan	46.9	50.7 (+8.1)	46.4 (−1.1)
11	Kefar Blum	33.7	38.0 (+12.8)	33.8 (+0.3)
12	Kefar Giladi	48.3	52.9 (+9.5)	47.3 (−2.1)
	Average total	41.8	43.6 (+4.3)	40.2 (−3.9)
	Average north	43.6	47.7 (+9.8)	43.3 (−0.4)

6. Discussion

Rainfall and temperature time series produced in the RCM-ICTP climate change simulation experiment over the EM are discussed and analyzed based on application of a statistical interpretation approach. Results of the analysis are mainly in agreement with those of Giorgi et al. (2004b). At the same time the analysis allows to address several problems related to the interpretation of the modeling results over North Israel. Special attention is given to understanding of the expected trends of extreme rainfall and maximum temperatures. The existence of a resemblance even to some fine detail between the projected winter (DJF) rainfall trends and the observed trends over the EM in the recent decades, is demonstrated. Particularly, the mixed negative and positive trends projected over the EM in B2 (Fig. 3, B2) seem to fit quite well mixed trends that were reported in the recent period (Alpert, 2004, Zhang et al., 2005) over the Middle East. As to the downscaling of maximum temperature and heavy rainfall, it is shown that two stations located within one model grid box, one over the mountain and the second over the valley, can exhibit quite different and still very realistic distributions. Another feature of the climate trend projected is an increase in the frequency of occurrence of intense rainfall events at the Israeli northern mountains stations — particularly in the simulation results according to B2 scenario with higher frequency of heavy rainfall events during autumn. In A2 scenario, however, an increase in the frequency of heavy precipitation events is projected during spring.

Thus, it may be concluded that the RCM-ICTP results project combination of more intense water stress with the increased inter-annual variability and more heavy rain events, which will make the water resources over the SE Mediterranean more vulnerable. The higher sensitivity to water stress will probably require development of improved systems for water management.

The analysis presented above was based on results of a single climate simulation experiment performed at the ICTP (Giorgi et al., 2004a,b). The climate modeling results are characterized however by an uncertainty, level of which is varying over the globe due to the variation of the relative roles of the climate-controlling factors. A multi-model approach has been suggested and applied in a European climate modeling effort under

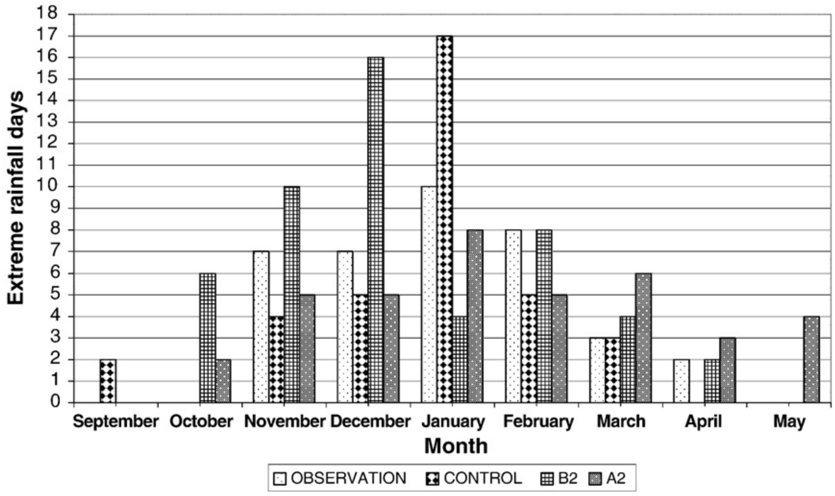

Fig. 9. The monthly distributions of the extreme rains (>50 mm/d) at the mountain station (Har Knaan), for the observations, control run (1961–1990), B2 and A2 runs (2071–2100).

the EU PRUDENCE Project (Christensen and Christensen, 2003; Giorgi et al., 2004a,b; Deque et al., 2005) to address the issue. In this project the EM area was covered however by only one of the RCM experiments (Giorgi et al., 2004a,b), results of which are used in the current study. A similar strategy has been recently adopted (Krichak et al., 2007) for RCM investigation of the climate change processes over the EM. In this

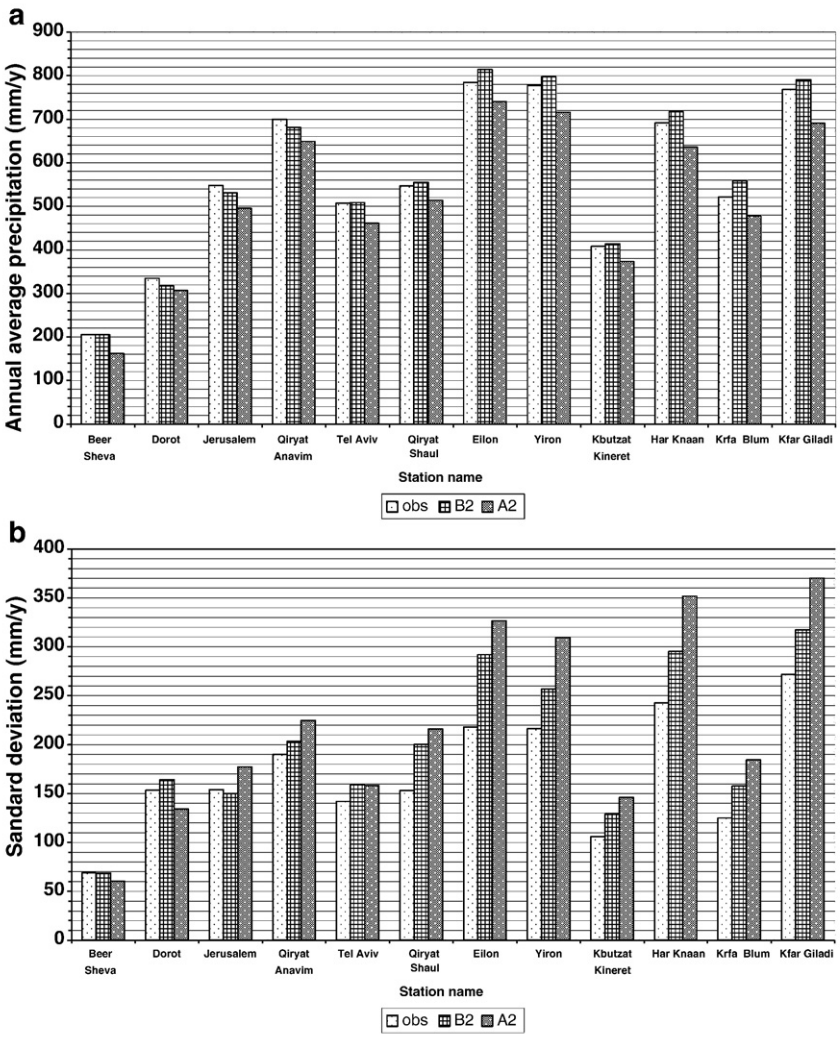

Fig. 10. a: The annual average precipitation (mm/yr) over 30 yr at 12 stations over Israel (see Fig. 4 for locations) for the observations, B2 and A2. The values for B2 and A2 include the factor corrections of the model bias, based on the control run against the observations (both are for 1961–1990). These factors were obtained by the ratios between the observed and control run annual averages rains (similar to the procedure applied in Table 1). b: As Fig. 10a but for the annual averages standard deviations (mm/yr) over 30 yr. Same model bias corrections as in Fig. 10a were applied.

experiment three sets of RCM simulations of the current (1961–1990) and future climates (2071–2100) over the EM have been performed using driving data from two different sources. A reasonable agreement of the results of the experiment with those of the RCM-ICTP, indicate a high enough level of reliability of the climate change projections reported.

7. Summary

Large-scale predictions over the Mediterranean suggest up to 35% rainfall reductions and 3–5 °C warming by 2071–2100. Our RCM findings over the EM support these and suggest further decrease in rainfall, increase in temperatures and a tendency to a more extreme climate. Much more detail can be derived from the RCM particularly with statistical interpretation as performed here over Israel with focus on a crucial small area, i.e., the Upper Catchment of the Jordan River, N. Israel. While most of the Mediterranean shows rainfall decreasing trends, there are rainfall increases over south/central Israel.

Results of the RCM simulations suggest a significant factor of increase in the number of the heavy rain days over Israel — the Jordan River basin. Averaged over the six stations in the north (except the station Eilon, all are in the JR Basin) there is an average rainfall increase of about 10% in the 95.5% centile especially in B2 (Table 1).

Finally, according to the coarse-resolution reanalysis data the recent observed summer temperature trends over the southeastern Mediterranean region have been maximized over the sea area. At the same time according to the RCM data – as well as to those from the global climate models – the trends are maximized over land. It is not fully clear yet if the disagreement is due to problems in the reanalysis data or due to limitations of the RCM models. This problem clearly needs further study.

Acknowledgements

This research is part of the GLOWA Jordan River Project funded by the German Ministry of Science and Education (BMBF), in collaboration with the Israeli Ministry of Science and Technology (MOST). The authors thank M. Deque for providing reference material on his statistical correction approach as well as F. Giorgi for providing results of the climate change simulation experiment performed with the RegCM2 regional climate model at the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy under the PRUDENCE Project EVK2-CT2001-00132 in the EU 5th Framework program for Energy, Environment, and Sustainable development.

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