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Long-term variations in summer temperatures over the Eastern Mediterranean

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[1] The inter-annual variation of the 850 hPa temperatures over the Eastern Mediterranean (EM) for July–August was analyzed for 1948–2002, using NCEP/NCAR reanalysis data. The time series of seasonal averages and the distribution of 'hot' and 'cool' days indicate the existence of three distinct warm periods. The warmest began in the mid-1990s. A long-term warming trend of 0.013 Ky^{-1} was found. The warming trend in July was 7 times greater than that of August, and July replaced August as the warmest month of the year. A trend of increasing extremity was also found. This was manifested in increasing seasonal standard deviation of daily temperatures, at a rate of 11% over 55 years, and in an increase in the frequency of both 'hot' and 'cool' days. These trends are also reflected in an increase in the seasonal maximum temperatures, which is 3 times greater than the increase in minimum temperatures. *INDEX TERMS:* 1610 Global Change: Atmosphere (0315, 0325); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620). **Citation:** Saaroni, H., B. Ziv, J. Edelson, and P. Alpert, Long-term variations in summer temperatures over the Eastern Mediterranean, *Geophys. Res. Lett.*, *30*(18), 1946, doi:10.1029/2003GL017742, 2003.

1. Introduction

[2] During the summer, especially in July and August, the Eastern Mediterranean (EM) is dominated by two persisting dynamic factors: subsidence [e.g., *Alpert et al.*, 1990; *Rodwell and Hoskins*, 1996] and north-westerly cool Etesian winds [e.g., *Air Ministry*, 1962; *Prezerakos*, 1984; *Saaroni and Ziv*, 2000]. The Standard Deviation (STD) of the lower-level temperatures, at 850 hPa, over the region attains its annual minimum, of 2.8 K, in July–August [*Saaroni and Ziv*, 2000]. Important feature, related to the above factors, characterizing the EM is a persisting inversion, which prevails over the region from June to September [*Dayan et al.*, 1988, 2002]. The inversion traps the lower level moisture and pollution and so enhances the heat stress and air pollution over the region. On the average, heat stress conditions, according to the definition of *Thom* [1959] and *Sohar* [1980], (i.e., the average of the dry- and wet-bulb temperatures) for July and August along the coastal plain of Israel prevails for 24 hours a day (moderate along 13 hours and in the rest - mild, *Bitan and Rubin*, [1994]). A warming trend in this region has, therefore, severe environmental implications.

[3] A global warming trend is noted for the last century, in particular along the last 25 years [*IPCC*, 2001], though varying considerably in space and season. In the EM the trend is not distinct for most of the year, but in the summer (JJA) it is noticeable, +0.06 – +0.1 Ky^{-1} (Figure 2.10c in *IPCC* [2001]).

[4] Studies of the EM region, based on surface stations and radiosonde, for the second half of the 20th century found also a general warming trend for the summer season, as listed in Table 1. The warming trends vary between 0.008 Ky^{-1} [*Nasrallah and Balling*, 1993; *Xoplaki et al.*, 2003] and 0.029 Ky^{-1} [*Ben-Gai et al.*, 2001]. These differences result from differences in the specific study periods and regions (Table 1). However, a cooling trend was found in Athens, Greece, which agrees with the trend for 1948–2002 found in the NCEP/NCAR data base (not shown), where a decrease trend is noted over the Balkan, the majority of Greece and western Turkey.

[5] This study evaluates the variations and trends of the lower-level temperature regime in the mid-summer months, July–August. These two months were chosen because they are the warmest [*Bitan and Rubin*, 1994], the driest and the most persistent in temperature [*Saaroni and Ziv*, 2000] and in their synoptic pattern [*Bitan and Saaroni*, 1992]. In order to cover synoptic scale processes, we choose as a data base the NCEP/NCAR CDAS-1 archive reanalysis data [*Kalnay et al.*, 1996; *Kistler et al.*, 2001], with 2.5° × 2.5° horizontal resolution, rather than the single station located at Bet Dagan, Israel. A discontinuity might have been introduced into this data set in 1974, when satellite measurements became available [*Kalnay et al.*, 1996]. Since we focus on the general features we refrain from dealing with different hours of the day and refer to the daily average temperatures.

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Table 1. Main Findings of Temperature Trend Studies for the Eastern Mediterranean and Israel

Reference	Study region	Study period	Data base/variables	Trend, Ky^{-1}
Nasrallah and Balling [1993]	Entire Mediterranean	1950–1990 JJA	Gridded datasets of surface temperature	+0.008
National Observatory of Athens [2003]	Athens, Greece	1931–1990 July August	Average surface temperature	−0.023
Ben-Gai et al. [1999]	40 stations distributed evenly over Israel	1964–1994 July–August	Maximum surface temperature	+0.026
			Minimum surface temperature	+0.021
Ben-Gai et al. [2001]	Bet Dagan, Mid-Israel	1964–1995 July–August	Average virtual temperature Radiosonde data	
			850 hPa	+0.029
			surface	+0.012
IPCC [2001]	Eastern Mediterranean	1976–2000 JJA	Average surface temperature	+0.06 – +0.1
Xoplaki et al. [2003]	Entire Mediterranean	1850–1999 June–September	Average surface temperature	+0.002
		1900–1999 June–September	Average surface temperature	+0.005
		1950–1999 June–September	Average surface temperature	+0.008
Present Study	32.5°N,35°E EM,	1948–2002 July–August	Average 850 hPa temperature	+0.0134
	10°×10° around 32.5°N,35°E	1948–2002 July–August	Average 850 hPa temperature	+0.0135

The term "surface temperature" refers to "surface air temperature" measured in standard screens.

[6] We chose the 850 hPa level as a reference level, because this level is situated above the prevailing inversion, and thus is not overly sensitive to near surface effects, such as urban effects.

[7] This study aims to evaluate the inter-annual and long term variations in the seasonal average and the extreme temperatures, based on the NCEP/NCAR data base, concentrating on the lower-levels rather than on the surface. Section 2 presents the inter-annual variations and the long-term temperature trend. Section 3 analyzes extremity in the temperature regime and its long-term trend. Section 4 summarizes the results and discusses their implications.

2. Inter-Annual Variations and Long-Term Trend

[8] The time series of temperature variation is presented in Figure 1. Each point denotes the average daily temperature in July and August for the respective season at the 32.5°N, 35°E grid point. It is worth noting that similar results, with a correlation of R = +0.96, were obtained when the sampling area was extended to 10° × 10° around that grid point. The 6-order polynomial curve (black, Figure 1), supported by a 5-year moving average (grey), indicates three distinct warm periods; the first in the 1950s, the second in the late 1970s and early to mid-1980s and the third, the warmest period, beginning in the mid-1990s. These results agree with *Xoplaki et al.* [2003], who found for the entire Mediterranean for June–September warm periods in the 1950s and the 1990s and a cool period in the 1970s.

[9] The long-term trend of the seasonal average temperature for the entire study period, 1948 to 2002, shows an increase of 0.013 Ky^{-1}, significant at the 92% level. These results are consistent with the trend of the average observed maximum and minimum temperatures at the surface level in Israel [*Ben-Gai et al.*, 1999] for 1964–1994, at $\sim$0.02 Ky^{-1}.

[10] In order to evaluate the sensitivity of the long-term trend found for the average seasonal temperatures to the arbitrariness of the ends of the study period, it was recalculated for sub-samples, cutting 5 years from the beginning of the period, from its end and from both. A warming trend was still found when both end years and the first 5 years were cut, but when the latest 5 years were cut a cooling trend was found. The period 1951–2000 was divided into 5 decades (i.e., 1951–60, 1961–70 etc.). The first 2 had cooling trends, though not significant whereas the latest showed a warming trend, most significant (99.5%), of 0.27 in 1971–80 and 0.32 Ky^{-1} in 1991–2000. These findings emphasize the central contribution of the latest decade in the general warming trend.

[11] The distribution of the daily temperatures for the study period, extracted for two 30-year periods, 1948–1977 and 1973–2002, separately (Figure 2), indicates an increase in the mode temperatures of about 0.5 K in the second period as compared with the first. The 30-year average for 1973–2002 indicates that July became the warmest month of the year, replacing August, which was the warmest in the first period, 1948–1977 (not shown). Thus, the peak of summer is reached earlier. The absolute maximum and minimum temperatures for the second period are both higher than those in the first period. It is worth noting that four of the five warmest years (1998, 2000, 2001 and 1996, in descending order) occurred within the last seven years,

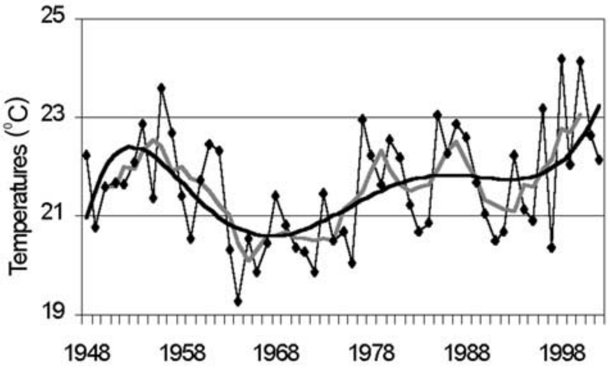

Figure 1. Time series of the 850 hPa temperature at 32.5°N, 35°E grid point, based on the NCEP/NCAR CDAS-1 archive. Each point denotes the average daily temperature in July–August for the respective summer. The grey curve is the 5-year running average and the black curve is the best-fitted 6-order polynomial. Note the good fit between the running average and the 6-order polynomial.

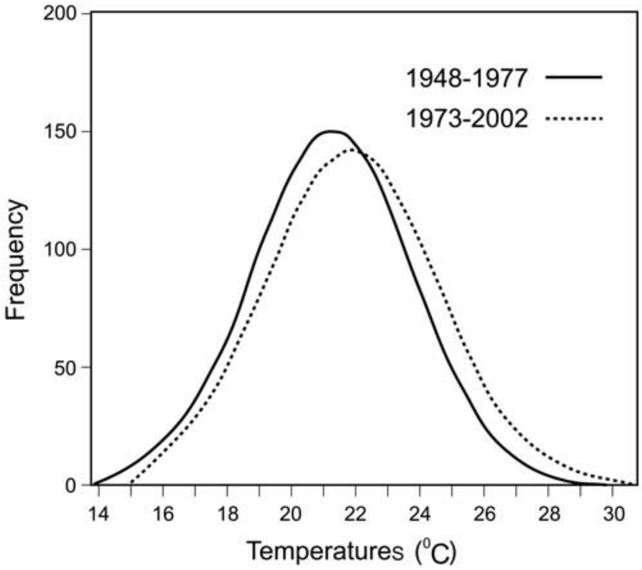

Figure 2. Distribution of 850 hPa daily temperatures at the 32.5°N, 35°E grid point for two 30-year periods: solid line: 1948–1977, dotted line: 1973–2002. The peak of each curve represents the mode temperature for the respective period.

which is consistent with the *IPCC* [2001] global surface temperature analysis.

3. Extremity

[12] The extremity of the temperature regime was examined for the grid point representing mid-Israel, 32.5°N, 35°E. As a first step we tracked the STD of the daily temperatures for each July–August. The variation is shown in Figure 3. A positive trend of 0.0044 Ky^{-1} (significant at the 85% level) was found, an increase of 11% in the STD of temperature during 55 years.

[13] A more detailed analysis was performed for the distribution of 'hot' and 'cool' days (i.e., days in which the 850 hPa daily average temperature deviated by more than 1 STD above or below the 1948–2002 average for July and August, respectively). Figure 4 shows the variations in the occurrence of 'hot' and 'cool' days. The inter-annual variation in the occurrence of 'hot' days is similar to that of the average seasonal temperature (Figure 1). In the most extreme case, year 2000 (belonging to the 4 warmest years), nearly 50% of the mid-summer days (29 out of 62) were 'hot'.

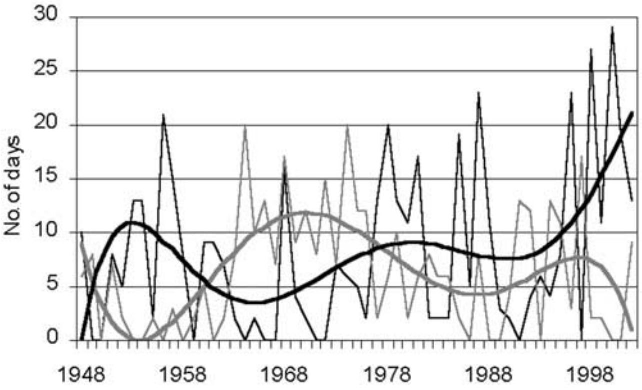

Figure 4. Time series of the number of 'hot' (black line) and 'cool' (grey line) days in July–August at the 32.5°N, 35°E grid point. Each point denotes the number of occurrences in the respective year. The curves denote the respective best fitted 6-order polynomial.

[14] The long-term trend in the number of days in each of the two groups is rather surprising. The trend for 'hot' days is positive (0.13 d y^{-1}, significant at the 97.5% level) and that of 'cool' days is also positive, though much smaller, 0.014 d y^{-1}, with a poor significance, at the 70% level. The trend of increasing both 'hot' and 'cool' days is a clear manifestation of increasing extremity. An increasing trend of the occurrence of 'hot' days agrees with *Ben-Gai et al.* [1999], who found an increase in the high tail of the surface maximum air temperature distribution.

[15] The trend of increasing extremity is also reflected in the time series of the seasonal maximum and minimum

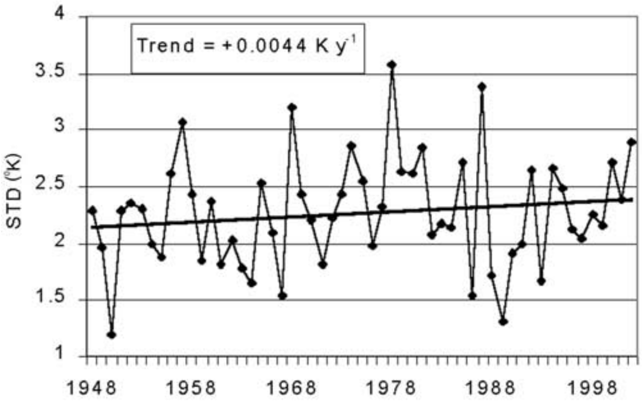

Figure 3. Time series of the standard deviation (STD) of the temperatures at 850 hPa for July–August at the 32.5°N, 35°E grid point. Each point denotes the STD of the daily-mean temperatures in July–August for the respective summer. The thick line is the linear trend.

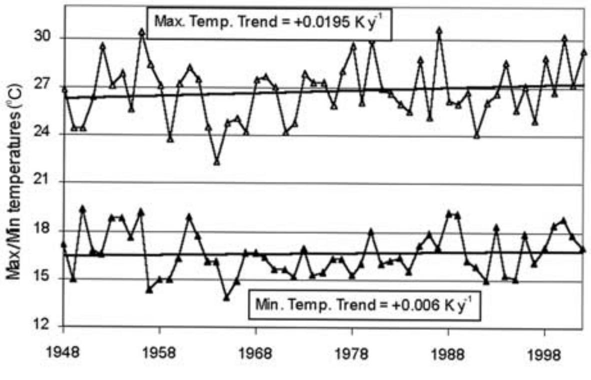

Figure 5. Time series of the seasonal 850 hPa maximum and minimum temperatures for July–August at the 32.5°N, 35°E grid point. Each triangle denotes the absolute maximum (empty) and minimum (full) temperature for the pertinent season. The thick lines are the respective linear trends.

temperatures (Figure 5). A warming trend can be seen in both, with values of 0.0195 Ky^{-1} (significant at the 90% level) for the maximum seasonal temperatures and 0.006 Ky^{-1} (significant at only 65% level) for the minimum. The trend in the seasonal maximum temperature is larger than that of the average temperature (0.013 Ky^{-1}), whereas that of the minimum temperature is less than 1/3 of the maximum. The above findings suggest that the increasing trend of the occurrence of 'hot' days has an important effect on the overall warming trend.

4. Summary and Discussion

[16] The lower level mid-summer temperature regime over the EM for 1948–2002 was studied. A long-term trend of average seasonal temperatures indicates a warming trend of 0.013 Ky^{-1}. The warming rate for July is 7 times larger than for August. The 30-year average for 1973–2002 indicates that July has become the warmest month of the year, replacing August, which was the warmest from 1948 to 1977.

[17] A pronounced signature of increasing extremity was noted, manifested by an increase in the STDs within the individual seasons, at a rate of 11% over 55 years, and in an increase in the frequency of both 'hot' and 'cool' days. This trend is also reflected in an increase in the seasonal maximum temperatures, 0.0195 Ky^{-1}, which is three times larger than the increase in the respective minimum temperatures.

[18] Since a high correlation between the 850 hPa temperature and heat stress over Israel was found, the increase in average temperature, together with increase in occurrences of 'hot' days implies that summer environmental conditions are becoming worse.

[19] *Otterman et al.* [2002] attributed the increasing trend of temperature over Europe to an increasing trend in the southerly component of the westerly winds prevailing there. The possible impact of the northwesterly Etesian winds on temperature in our study region and level was evaluated through the inter-annual variation of the average seasonal wind vectors. A minor backward shift in direction was found, 0.07 deg y^{-1} ($R = 0.11$, significant at the 77% level), whereas the direction remained in the limits of 293°–339°. However, a significant decreasing trend in wind speed, 0.042 $m\ s^{-1}\ y^{-1}$ ($R = 0.63$, significant at the 99.5% level) was noted. The weakening trend of the Etesian winds, implying a reduction in the prevailing cool advection from northwest, can explain, at least in part, the warming trend over the EM.

[20] The warming trend can be attributed also to the increase in the frequency of 'hot' days, with no full cancellation by the 'cool' ones. The increase in the mode temperature of 0.5 K between 1948–1977 and 1973–2002 indicates that the warming trend is partitioned between the net contribution of the 'hot' days and the warming of the 'ordinary' days themselves, as can be deduced from the distributions of the two periods (Figure 2). This suggests that the increase in extreme events can be considered as resulting from an increase in synoptic situations favored for extreme hot conditions over the EM, as can be inferred from the weakening trend in the Etesian winds. The contribution of dynamic conditions (i.e., trend in the distribution of synoptic patterns), to the warming trend over the entire Mediterranean is shown also by *Xoplaki et al.* [2003]. The warming trend of the 'ordinary' days can be considered as reflecting changes in the radiative balance over the region (i.e., direct greenhouse warming).

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