GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L12706, doi:10.1029/2005GL022796, 2005

Indications for aggravation in summer heat conditions over the Mediterranean Basin

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Received 23 February 2005; revised 11 April 2005; accepted 27 April 2005; published 28 June 2005.

[1] The summer temperature variations over the Mediterranean Basin were studied through the 850 hPa level for the months June–August along the period 1948–2003, based on the NCEP-NCAR CDAS-1 archive. The most prominent feature found is warming, larger than the global value, over the majority of the study region with a maximum of 0.04 Ky^{-1} over Sicily. At the same time, cooling was noted over Algeria and the Balkans. The trend for the 10% upper quantile of the days over the warming region was found larger than the seasonal, reaching 0.053 Ky^{-1}, implying that heat waves lead the general long-term trend. The shape of the long-term curve was found to fit the global one over the warming region. No synoptic-dynamic factor was found to account for the intensity and spatial distribution of the warming trend. This, together with the fit of the trend with the global one, suggests that the Mediterranean Basin manifests the increase in the greenhouse effect in the summer season.

Citation: Ziv, B., H. Saaroni, A. Baharad, D. Yekutieli, and P. Alpert (2005), Indications for aggravation in summer heat conditions over the Mediterranean Basin, *Geophys. Res. Lett.*, *32*, L12706, doi:10.1029/2005GL022796.

1. Introduction

[2] A global warming trend has been noted for the last century, in particular along the last 3 decades, though varying considerably in space and season [*Intergovernmental Panel on Climage Change* (*IPCC)*, 2001]. The warming trend of the summer surface air temperature over the Mediterranean Basin (MB) and southern Europe for the period 1950–1999 was 0.008 Ky^{-1} [*Xoplaki et al.*, 2003], and reached the value of 0.01 Ky^{-1} for 1976–2000 [*IPCC*, 2001, Figure 2.10c], one of the highest rates over the entire globe. The high summer average daily maximum temperatures along the Mediterranean dense populated coastal plains, reaching 30°C, combined with the high relative humidity [*Wallen*, 1977], implies that heat stress conditions prevail there. Therefore, any further warming in this region has far reaching environmental implications, so that the long-term trend of the temperature regime in this sensitive region needs to be investigated in detail.

[3] During the last two decades Western Europe suffered from severe summer heat waves with extreme maximum values on the summer of 2003 [*Le Comte*, 2004; *Luterbacher et al.*, 2004; *Meehl and Tebaldi*, 2004]. The spatial distribution of the 925 hPa level temperature anomaly for June–August 2003 over the MB (based on NCEP/NCAR data base; Figure 1) shows a maximum of over 4.5° over the western Mediterranean region. Similar results were obtained for the surface and 850 hPa levels.

[4] The long-term trend in the temperature regime over the MB, covering 25°N–45°N, 0°–40°E, is studied along the period 1948–2003 for the months June, July and August (JJA), using the 850 hPa level. Following *Saaroni et al.* [2003], we chose the 850 hPa level as representing the lower-levels, because it is not overly sensitive to near surface effects, such as the urban effects (as shown by *Kalnay and Cai* [2003]). The database is the NCEP-NCAR CDAS-1 archive [*Kalnay et al.*, 1996; *Kistler et al.*, 2001].

[5] Section 2 presents the long-term trend of the seasonal temperature and compares their temporal variations with the yearly global trend. Section 3 examines the trend of extremity, concentrating on the contribution of heat waves, and the last section discusses and summarizes the results.

2. Long-Term Trend of the Seasonal Average Temperature

[6] The spatial distribution of the long-tem linear trend of the seasonal temperature was extracted by mapping the slope of the best-fit straight line for each grid point along the study period (Figure 2). A warming trend was found over the majority of the MB. Two pronounced maxima can be noted. The most pronounced one is at the western Mediterranean (0.04 Ky^{-1} maximum) and the second over northern Egypt (0.034 Ky^{-1} maximum). In addition, two weak negative centers, reflecting a cooling trend, were found over the Balkans (-0.008 Ky^{-1}) and over Algeria (-0.015 Ky^{-1}). The cooling over the Balkans is consistent with the significant cooling over Greece along 1951–1985 found by *Reddaway and Bigg* [1996]. A similar distribution was found for each of the 3 individual months, among which the most extreme values were obtained for July (0.047 Ky^{-1} maximum). Figure 3 shows the spatial distribution of the confidence-level of the linear trend. The area that has the maximum confidence level, >0.95, is rather similar to that which experience the most intense warming (Figure 2). In addition, high confidence level (>0.95) is found in the middle of the cooling region over Algeria.

[7] In order to examine the course of the temperature trend the curve that best fits the temperature time series was derived for each grid point in the study area, using the locally weighted scatter-plot smoother (LOWESS)

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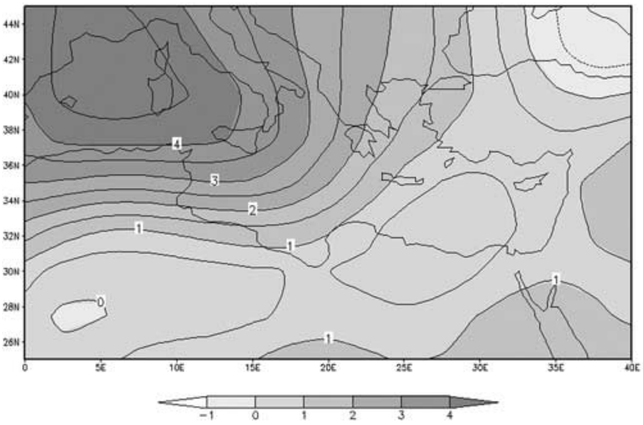

Figure 1. 925 hPa temperature anomaly for JJA, 2003, based on the NCEP-NCAR CDAS-1 archive [*Kalnay et al.*, 1996; *Kistler et al.*, 2001]. See color version of this figure in the HTML.

[*Chambers et al.*, 1983; *Cleveland*, 1979], belonging to "S-plus" functions (S-PLUS® 6.2 for Windows, copyright 1988, 2003 Insightful Corp.). A window, depending on an *f* - parameter, i.e., the fraction of data smoothed around each point, is placed about each x value. Points that are inside the window are weighted so that those nearby points get the largest weights. In general, the larger the *f*, the smoother is the fit. Here we used $f = 0.8$. The same procedure was applied to the mean global annual temperature time series for 1950–2001 [*IPCC*, 2001].

[8] The global yearly curve (Figure 4a) shows a slow warming trend from 1950 to the early seventies, with a slope of $\sim$0.003 Ky^{-1}, when it turns and attains a slope of $\sim$0.016 Ky^{-1} for the period beginning at 1974 and ending at 2001. Figure 4b shows the spatial distribution of the shapes of the seasonal long-term trend curves for the grid points over the study region. The region in which the curve shape is similar to the global one overlaps, more or less, that where the maximum warming rate was found (Figure 2). This region covers the majority of the MB and to its south, especially along its eastern part, where north-westerly winds prevail [e.g., *Ziv et al.*, 2004]. The region in which the long-term curve shows the inverse shape of the global one (sloping up along the first part of the study period, then turning down) almost coincides with the cooling region found over Algeria.

[9] The degree of similarity between the global and the MB long-term trends was further examined by correlation maps between the seasonal time-series at each grid point in the study region and the global yearly ones (not shown). The correlation yielded positive values over the majority of the study region with two maxima, >+0.64 over Egypt and >0.5 over the western Mediterranean, the regions where the highest warming trends were found. Negative values were found over Algeria, where a negative trend was observed. When the time-series were smoothed, the distribution remained the same and the amplitude increased. When each individual temperature was replaced by the 9-year moving average the positive correlation over the MB attained +0.9 (over its western part) and −0.78 over Algeria.

[10] The above findings indicate that in the summer season the MB has an affinity to the global temperature course in two aspects: one is the sign of the long-term linear trend (but with a higher rate) and second is the shape of the trend curve.

3. Extremity and Contribution of Heat Waves

[11] The environmental aspects of the warming trend are not fully captured by the average seasonal temperatures alone, but also by analyzing the occurrences of hot events (heat waves). These are represented here by the 10% upper quantile of the days. The spatial distribution of the long-term trend for these days (Figure 5) is similar to that of the seasonal average (Figure 2), except for larger amplitude, e.g., a maximum of 0.053 Ky^{-1}, as compared to 0.04 Ky^{-1} for the seasonal average (western Mediterranean), and −0.017 Ky^{-1} against −0.009 Ky^{-1} (Algeria). As was found for the average monthly temperature, the trend of the 10% upper quantile was the largest in July, being 0.069 Ky^{-1} over Sicily. This emphasizes that the increase in the frequency of heat waves play a central role in the warming

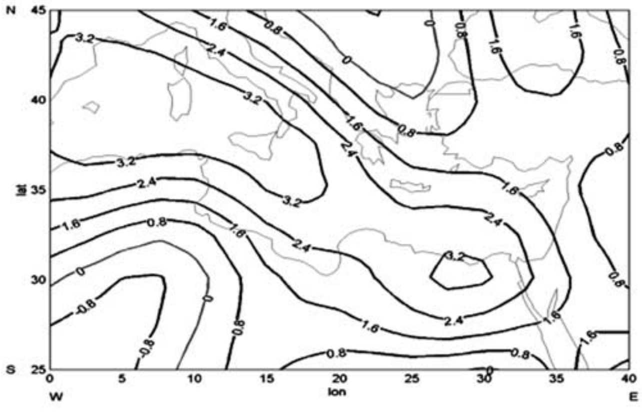

Figure 2. Long-term trend for the seasonal (JJA) 850 hPa temperature (K/100y) for 1948–2003, based on the slope of the best-fit straight line for each grid point.

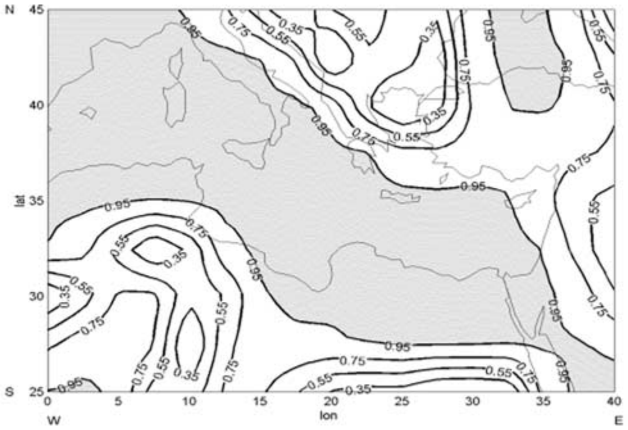

Figure 3. The spatial distribution of the confidence-level of the linear trend. Areas with confidence level >0.95 are shaded.

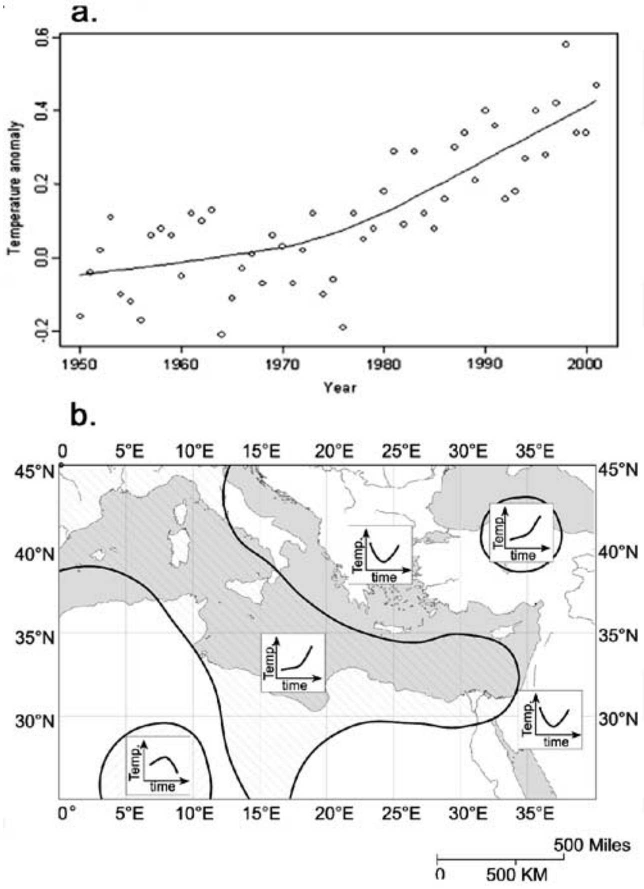

Figure 4. (a) Global surface yearly temperature (K) anomaly with respect to 1950–1980 average [*IPCC*, 2001] and the curve that approximates the long-term trend, using LOWESS method [*Chambers et al.*, 1983; *Cleveland*, 1979], with f-parameter of 0.8. (b) Spatial distribution of the shape of the long-term curve trends of the 850 hPa temperatures over the study region.

trend, where observed and that the reverse holds for the cooling regions.

[12] The respective distribution for the 10% lower quantile (not shown) indicates also a warming trend, implying a reduction in cool days, over the warming region. However, the warming trend of the lower tenth is rather smaller than that of the upper tenth, suggesting that the temperature regime is becoming more extreme there. An opposite trend was found in the cooling regions.

4. Summary and Discussion

[13] The long-term trend of the summer temperature regime (JJA) for 1948–2003 over the MB was studied. The most prominent feature found is the long-term warming over most of the study region, with a maximum of 0.04 Ky^{-1} over Sicily, i.e., 4 times larger than the global average rate (0.01 Ky^{-1}). At the same time, cooling trend was found over Algeria and over the Balkans.

[14] The magnitude of the linear long-term trend of the 10% upper quantile of the days was found larger than the seasonal average in both the warming and cooling regions. This implies that heat waves lead the general trend, and that the regions subjected to general warming are also subjected to an increasing burden of heat waves. Similar results, both for the seasonal averages and the upper tenth days, were found for each of the pertinent months separately, with July being the most extreme. This tendency agrees with *Meehl and Tebaldi* [2004] prediction for the 21st century.

[15] A similarity between the long-term course of the global temperature and that over the majority of the MB, was manifested by the long-term curve, combined of mild warming up to the seventies, then gaining a pronounced upward slope. This similarity was further validated by the correlation between the global time-series and that averaged over the region in the MB that has the same long-term course, being +0.67. The respective correlation for the entire Mediterranean Sea yielded also a significant correlation, of +0.61.

[16] A comparison between the spatial distribution of the long-term linear trend over the MB with the future trend calculated by *Meehl and Tebaldi* [2004] indicates that the regions which were found to cool, i.e., the Balkans and Algeria, coincide more or less with the regions that are expected to experience the most intense warming in the 21st century. This trend reversal may be explained in two alternative ways. One is that the observed cooling is the negative phase of climatic oscillation, in which the positive counterpart will take place on the 21st century and other is that the climatic prediction model used missed a regional unique process, which has caused cooling in these regions.

[17] *Simmons et al.* [2004] showed that the NCEP/NCAR data yielded a warming trend smaller than those obtained by the CRU and the ERA-40 data sets for the period 1979–2001, but an intermediate trend for the period 1958–2001. The absence of a consistent error and the high inter-annual correlations among the temperatures in these data sets for Europe (>0.98 for each pair) [*Simmons et al.*, 2004] indicate that our results are valid.

[18] In order to examine to what extent the 850 hPa NCEP/NCAR gridded data fit the surface temperatures based on GISS data used by *Luterbacher et al.* [2004] we calculated the long-term linear trend for the region and period they used (35°N–70°N, 25°W–40°E, JJA 1976–2003). We obtained +0.050 Ky^{-1} for the 850 hPa, which is

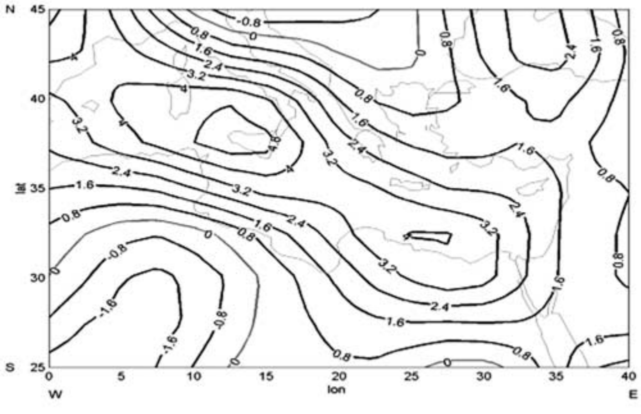

Figure 5. As for Figure 2 but for the upper tenth temperatures.

slightly smaller than the value of $+0.067\ \mathrm{Ky}^{-1}$ they obtained for the surface air temperatures. This reflects a reasonable degree of agreement between both data sources and suggests that the difference may be attributed to the contribution of the urban effect.

[19] The magnitude of the warming trend over the MB, being considerably higher than the global one, suggests that synoptic scale factors may also play a significant role in that trend. *Xoplaki et al.* [2003] found that "three large-scale predictor fields (300 hPa geopotential height, 700–1000 hPa thickness and Mediterranean SSTs) account for more than 50% of the total summer temperature variability". We examined the long-term trend of the dynamic factors, which directly affect the temperature regime, i.e., vertical velocity and lower level advection. The only finding which partly supports the above hypothesis was a general weakening trend found in the 850 hPa wind speed for JJA (not shown), implying a weakening of the seasonal lower-level cool advection characterizing the MB [*Alpert et al.*, 1990; *Saaroni and Ziv*, 2000; *Saaroni et al.*, 2003; *Ziv et al.*, 2004]. But, when this was examined for each of the pertinent months separately, no consistent trend was found. Furthermore, in July, in which the warming trend is the most pronounced, a strengthening of the lower level wind was observed. Regarding vertical velocity, over most of the warming regions a weakening trend of subsidence was found. We, therefore, cannot point at any dynamic factor that can explain the extreme warming trend found.

[20] The warming trend found in the summer season over the majority of the MB, the similarity between its long-term course and that of the global one and the absence of dynamic factors responsible for, suggest that the increase in the greenhouse effect, that affects the entire globe, affects also the MB in the summer, and even more intensely. This idea is supported by the clear sky in the summer season over the MB, which frees the region from a negative feedback of clouds. However, such an issue requires further, quantitative, investigation.

[21] The results and trends shown here indicate that the MB, which is subjected to a considerable heat stress in the summer season, may suffer from further aggravation in the summer heat stress and extreme heat waves that claim more lives, as happened in Western Europe in the summer of 2003. The warming process in dense populated regions is expected to be even faster near the surface due to the urban heat island, which is enhanced, at least partly, by energy emitted from air conditioners.

[22] **Acknowledgments.** This study is supported by the Israeli Science Foundation (ISF, grant no. 828/02). Partial support is due to the GLOWA-JR funded by the BMBF and Min. of Sci. (MOS), Israel. Also, by the EU project DETECT. Special thanks are due to Orna Zafrir-Reuven for drawing Figure 4b.

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