Theor. Appl. Climatol. 61, 55–68 (1998)

Theoretical and Applied Climatology

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Annual and Seasonal Climatic Analysis of Surface Air Temperature Variations at Six Southern Mediterranean Stations

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With 5 Figures

Received October 3, 1997
Revised April 17, 1998

Summary

Variations of surface temperature are studied at six southern Mediterranean stations: Marakesh (1910–1991), Alger (1823–1991), Tripoli (1944–1991), Alexandria (1942–1991), Amman (1923–1991), and Beirut (1863–1991). The homogeneity of the temperature data is examined for each station by means of the short-cut Bartlet test. Abrupt climatic changes towards warm or cold periods exist at all stations with the exception of Tripoli. Persistence is also found in annual and seasonal temperatures, however, this persistence is not always linear. Annual and seasonal temperature fluctuations are examined and periods important warming begin in 1910 and 1970. Fluctuations in winter temperature are around the mean value, while summer temperatures, during the last three decades, have been distinctly higher than the long term mean values.

1. Introduction

Many studies have investigated surface air temperature change because variations in this parameter are thought to be indicative of climatic fluctuations and change. Over the past 30 years, this problem has been tackled by researchers producing estimates of changes or trends for either regional averages, or individual stations in cities (Mitchell, 1953, 1961; Landsberg, 1970; Ludwig and Kealoha, 1968; Manley, 1974; Schönwiese, 1978, 1979; Currie, 1981a, b; Katsoulis, and Theoharatos, 1985; Katsoulis, 1987 and Folland et al., 1990).

Few studies exist concerning temperature variations over long periods which cover the whole Mediterranean region (Wigley and Farmer, 1982; Schönwiese, 1978, 1979). Arseni and Maheras (1991) performed a statistical analysis of air temperature variations at four Mediterranean stations (Marseille, Rome, Athens, and Jerusalem) and found an abrupt climatic change toward a warm period. These changes took place at Marseille in about 1942, at Rome in about 1893 and at Jerusalem in 1920. Persistence also appears to be significant for annual temperatures, and for seasonal temperatures it was found that summer exhibited the greatest levels of persistence.

Many researchers have studied temperature variations at single stations in the Mediterranean region, such as the studies of Arseni (1973), Metaxas (1974), Repapis (1984), and Katsoulis (1987) for Athens, Meini et al. (1979) for Livorno, Colacino and Rovelli (1983) for Rome, Repapis and Philandras (1988) for the eastern Mediterranean, and Maheras (1989a) for the western Mediterranean area.

In this paper, a statistical analysis of annual and seasonal surface air temperature variations at six stations in the southern Mediterranean area is presented. The homogeneity of the temperature data, identification of abrupt climatic changes,

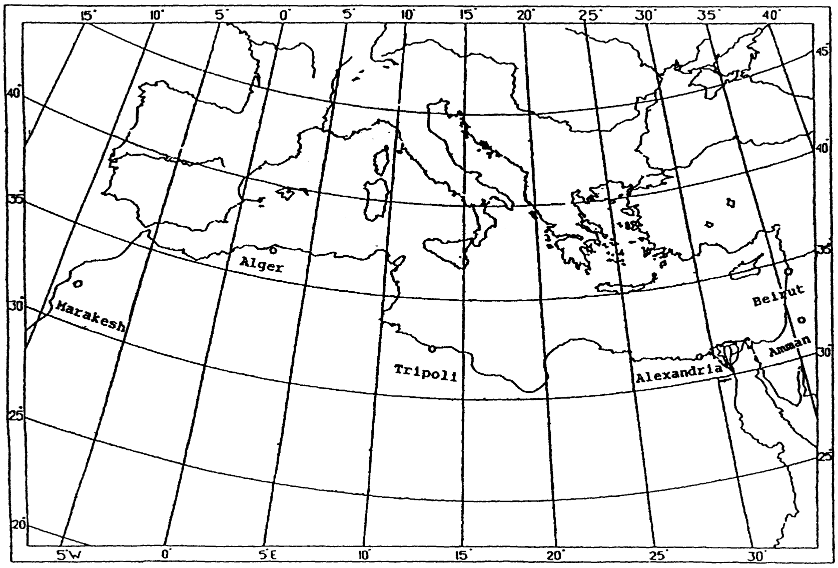

Fig. 1. Map of the locations of six stations for the southern Mediterranean region

their persistence, and their fluctuations are examined.

2. Data

Monthly mean surface air temperature observations at six southern Mediterranean stations (nearly equidistant) situated in the western, central and eastern Mediterranean area (Fig. 1) were used: Marakesh (31.6° N, 8.0° W) from 1910 to 1991, Alger (36.7° N, 3.3° E), from 1823 to 1991, Tripoli (32.9° N, 13.2° E) from 1944 to 1991, Alexandria (31.2° N, 29.8° E) from 1942 to 1991, Amman (32.0° N, 35.9° E) from 1923 to 1991, and Beirut (33.9° N, 35.5° E) from 1863–1991. The sources of data are: Archive of Egyptian Meteorological Authority, Archive of Libyan Meteorological Authority, and Carbon Dioxide Information Analysis Center (CDIAC).

Monthly mean values of surface air temperature are computed from their corresponding daily values calculated from the maximum and minimum temperatures over the month, $T = (T_{\max} + T_{\min})/2$. The few missing data for some stations were interpolated using the minimum curve method.

3. Results

3.1 Homogeneity

Lack of homogeneity in data series creates a big problem for researchers who study time series analysis. Climatic elements could be affected by changes in instrumental exposure, station loca-

Table 1. *Bartlet Test (Short-cut) Result for Six Mediterranean Stations (n is the Number of Terms in each Sub-period k, and k is the Number of the Sub-period)*

Station	95% Significance point	S^2_{max}/S^2_{min}				
		Year	Winter	Spring	Summer	Autumn
Marakesh n = 27, k = 3	2.46	2.10	1.22	1.30	1.31	0.90
Alger n = 23, k = 6	3.67	3.60	3.50	4.90	3.00	3.52
Tripoli n = 16, k = 3	3.54	2.10	1.22	1.30	1.31	2.95
Alexandria n = 16, k = 3	3.54	1.39	1.76	3.41	2.42	2.04
Amman n = 33, k = 3	2.38	3.02	1.61	3.24	1.51	4.58
Beirut n = 25, k = 6	3.67	3.22	2.31	3.96	3.57	3.54

tion, and the method of estimating daily and monthly averages. Here, we use the short-cut Bartlet test (Mitchell et al., 1966) to examine the homogeneity of the surface air temperatures at the six southern Mediterranean stations.

The short-cut Bartlet test is applied by dividing the series into k equal sub-periods, where $k \geq 2$. In each of these sub-periods we calculate the sample variance, that is, the quantity

$$S_k = \frac{1}{n}\left[\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2\right] \qquad (1)$$

where the summations range over the n values of the series in the sub-period k. From these values of s_k^2, we select the largest, denoted by $s_{\max}^2$, and the smallest, denoted by $s_{\min}^2$. The 95% significance points for the ratio $s_{\max}^2/s_{\min}^2$ can be obtained by comparing this ratio with the values given in the Biometrika table 31 (Pearson and Hartley, 1958).

The major parts of the time series examined seem to be homogeneous (Table 1). Some exceptions of homogeneity were found for Alger, Amman, and Beirut, especially in spring.

3.2 Abrupt Climatic Changes

The identification of an abrupt climatic change can be made by using the sequential version of the Mann-Kendall rank statistic (Mitchel et al., 1966; Sneyers, 1975). This test seems to be the most appropriate method for analyzing climatic changes in climatological time series (Goossens and Berger, 1986). To use this test we need to consider only the relative values of all the terms in series X_i under analysis. For this reason, it is necessary before applying the test to replace the X_i by their ranks Y_i arranged in increasing order. For each element Y_i, the number n_i of elements Y_j preceding it $(i > j)$ is calculated such that $Y_i > Y_j$.

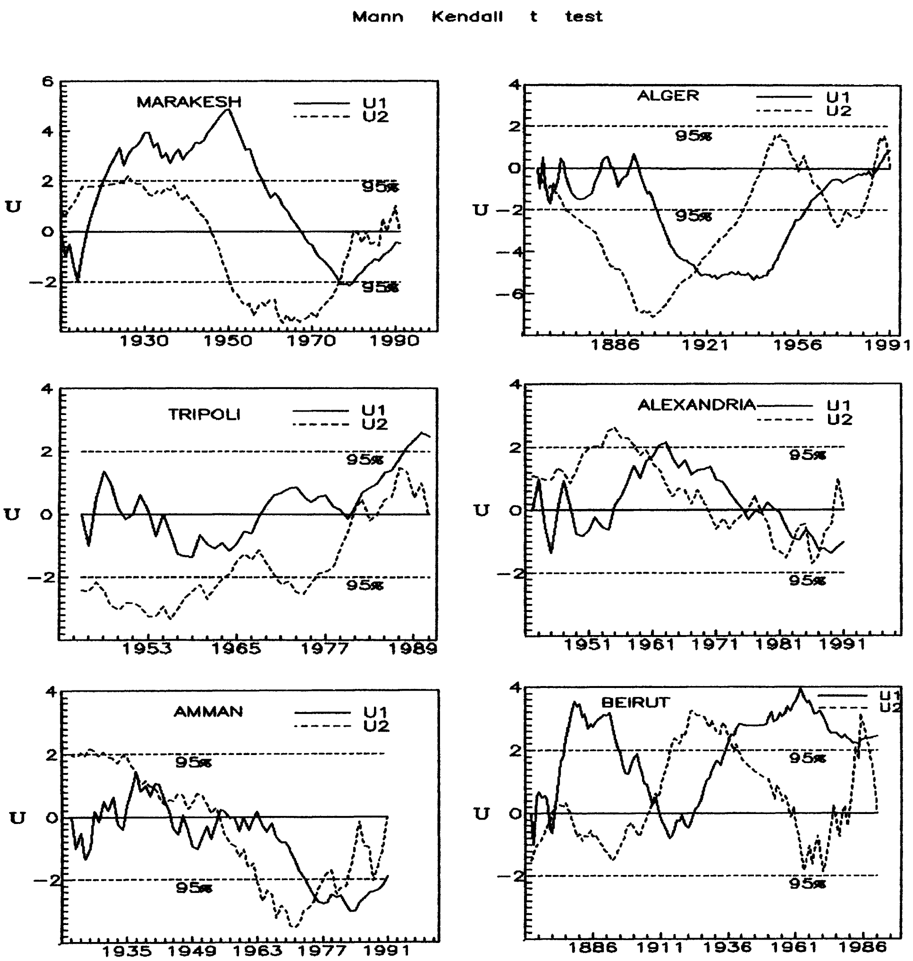

Fig. 2. Abrupt changes in the annual temperature time series as derived from the sequential version of the Mann Kendall test. (U1 forward sequential statistic and U2 backward sequential statistic)

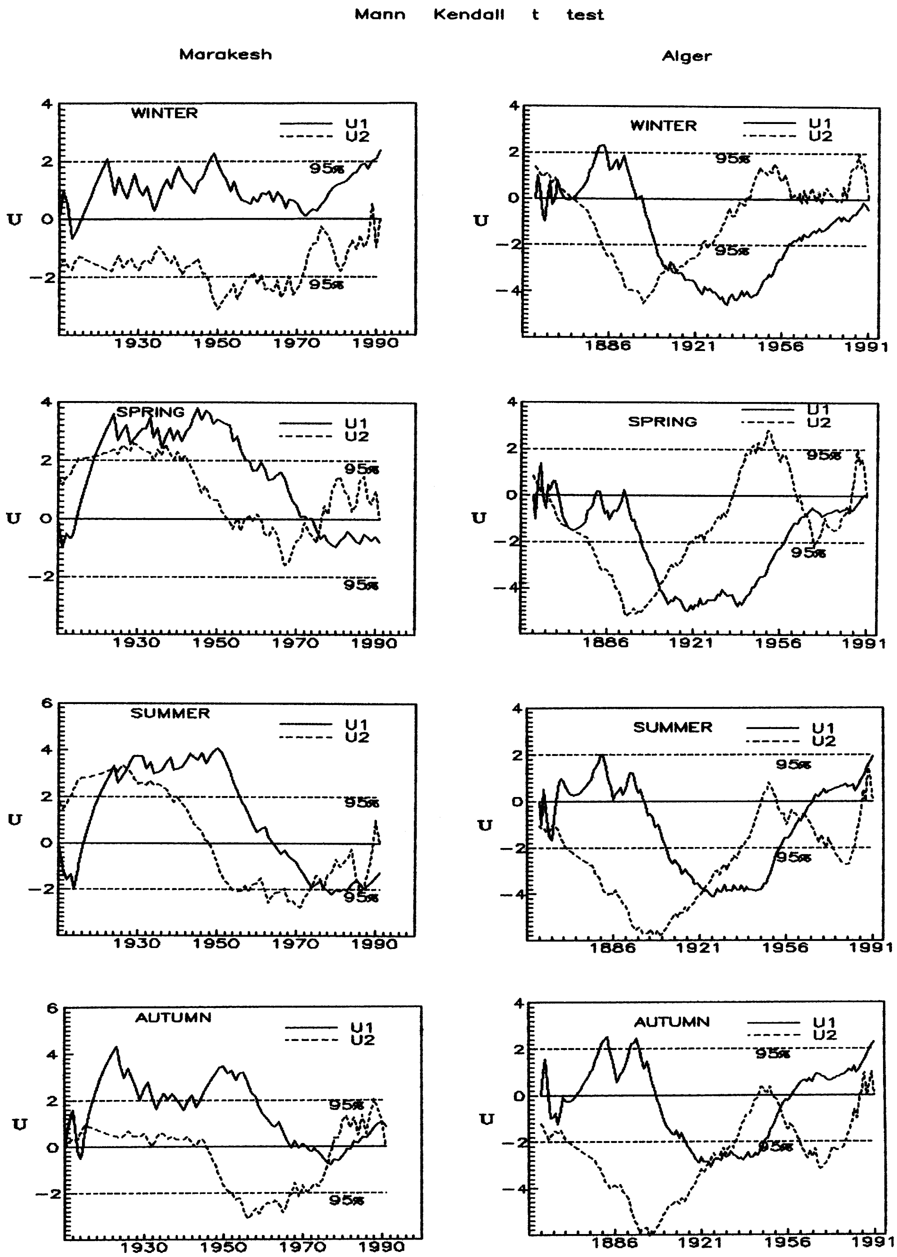

Fig. 3a. Abrupt changes in the seasonal temperature time series for Marakesh and Alger as derived from the sequential version of the Mann Kendall test. (U1 forward sequential statistic and U2 backward sequential statistic)

The statistical test t_i is then given by the equation;

$$t_i = n_1 + n_2 + \cdots\cdots\cdots\cdots + n_i \tag{2}$$

and its distribution function under the null hypothesis is asymptotically normal, with mean and variance;

$$E(t_i) = \frac{i(i-1)}{4}, \qquad \mathrm{var}\,(t_i) = \frac{i(i-1)(2i+5)}{72} \tag{3}$$

It is clear that in the absence of any assumptions regarding the existence of a trend in a given direction, the test is correct only if its two-sided form is adopted, that is to say if the null hypothesis is rejected for large values of $|t_i|$. In these conditions, after having calculated t_i, it is useful to determine the probability α_1, by the means of the standard normal distribution table, such that:

$$\alpha_1 = p(|u| > |u(t_i)|) \tag{4}$$

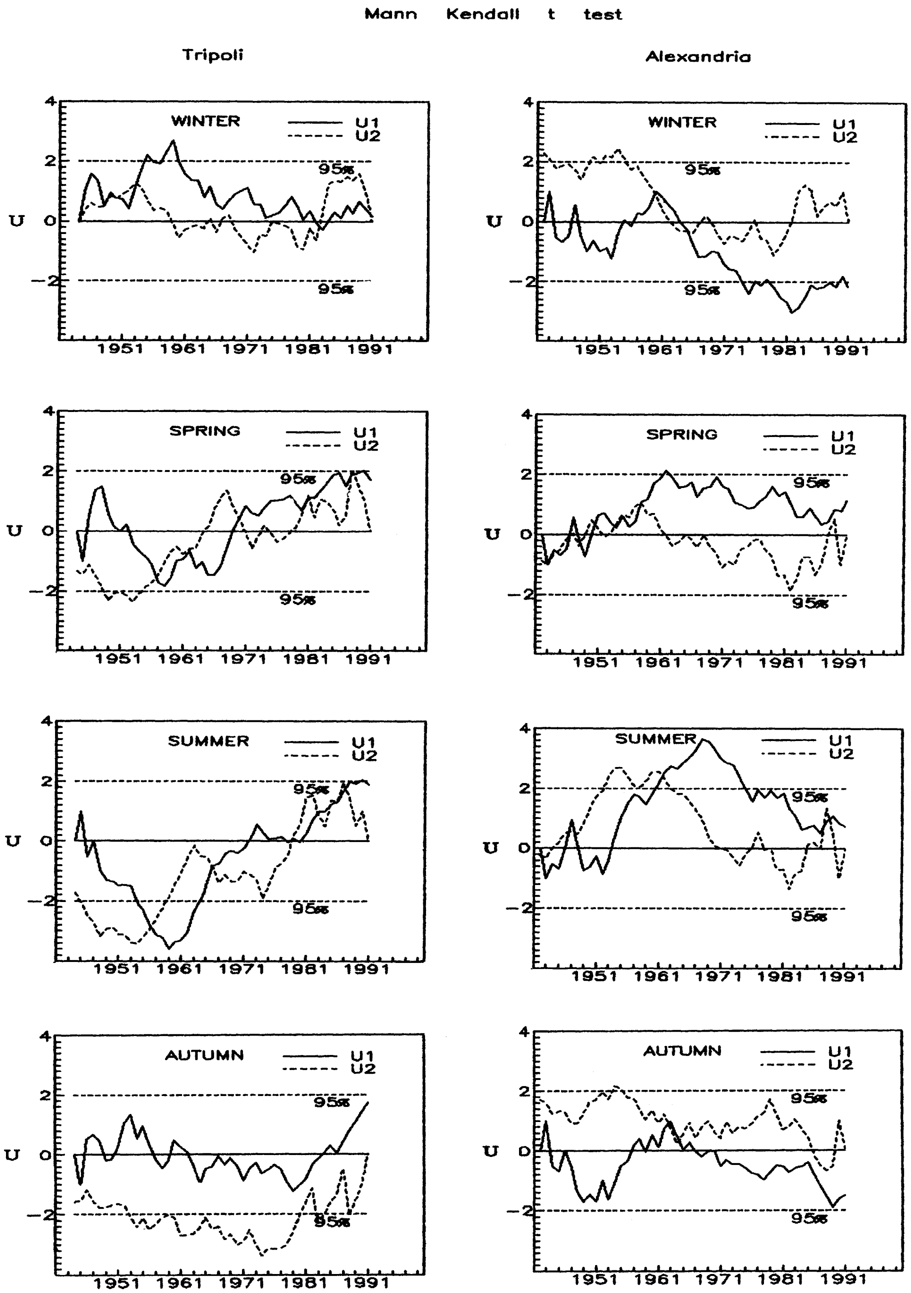

Fig. 3b. Abrupt changes in the seasonal temperature time series for Tripoli and Alexandria as derived from the sequential version of the Mann Kendall test. (U1 forward sequential statistic and U2 backward sequential statistic)

where

$$u(t_i) = [t_i - E(t_i)]/\sqrt{\text{var}\,(t_i)} \quad (5)$$

The null hypothesis is accepted or rejected at the level α_o (e.g. 0.05) depending on whether we have $\alpha_1 > \alpha_0$ or $\alpha_1 < \alpha_0$.

When the values of $u(t_i)$ are significant, an increasing or decreasing trend can be observed depending on whether $u(t_i)$ is increasing or decreasing. However, when a series shows a significant trend we wish to locate the start of the phenomenon by means of a sequential analysis. In this case, it can be usefully extended to the reversed series. Therefore, we calculate the number n'_i of Y_j terms for each Y_i term, such that $Y_i > Y_j$ with $i < j$, which gives a check on the first calculation, since we have;

$$n'_i = Y_i - 1 - n_i \quad (6)$$

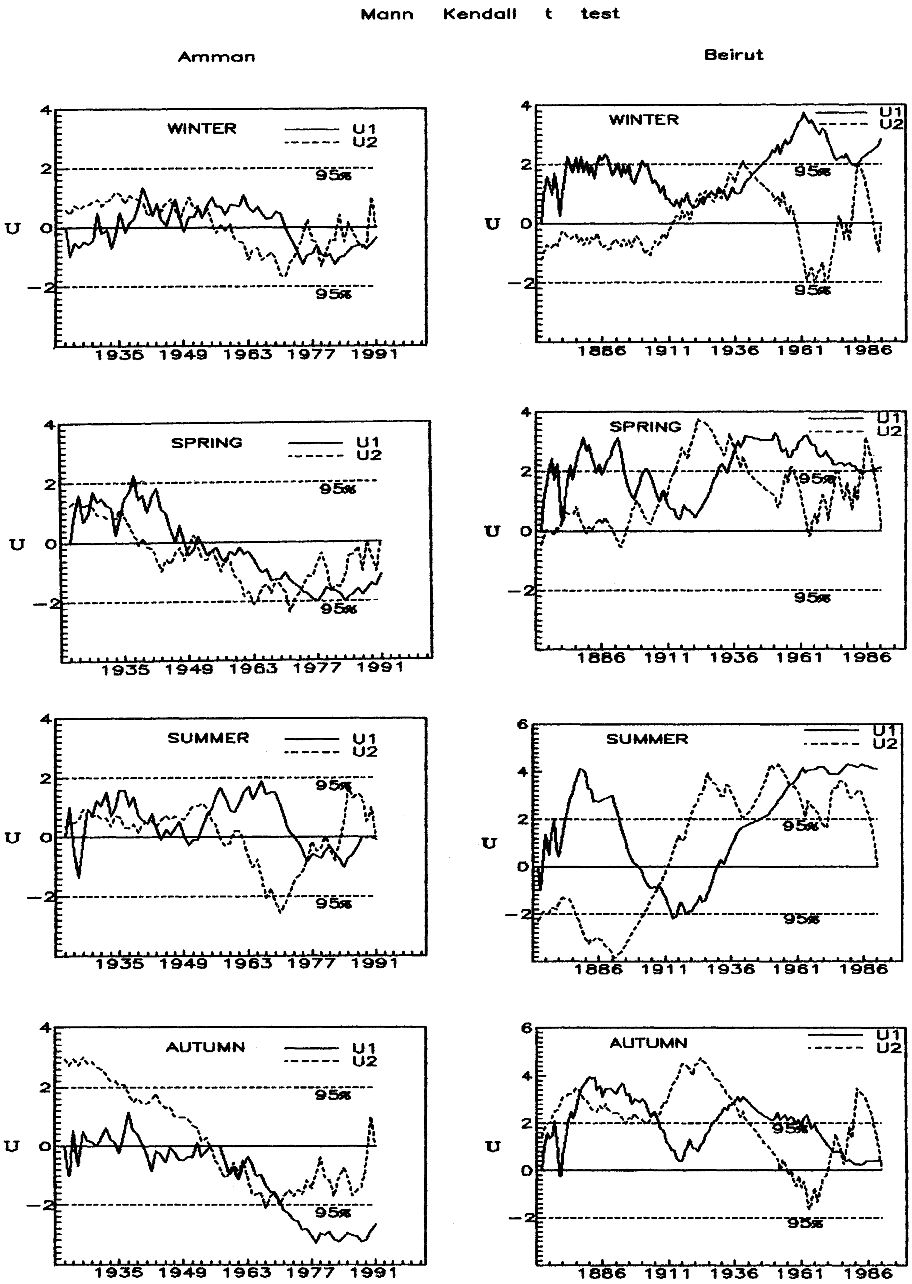

Fig. 3c. Abrupt changes in the seasonal temperature time series for Amman and Beirut as derived from the sequential version of the Mann Kendall test. (U1 forward sequential statistic and U2 backward sequential statistic)

so that

$$i' = (N + 1) - i, \tag{7}$$

where N is the total number of the series. Therefore the values of $u'(t_i')$ for the reversed series can be calculated similar to $u(t_i)$ as mentioned above.

In the absence of any trend in the series, the graphical representation of u and u' in terms of i generally gives curves which overlap several times. However, in the case of a significant trend, the intersection of these curves enables the start of the phenomenon to be located approximately.

Figure 2 shows the Mann-Kendall t test for the annual surface temperatures at the six stations. It is shown that for all stations (except Tripoli) a significant abrupt climatic change took place. Marakesh, Alger, and Beirut show a change towards a warming. The beginning of the phenomenon varies from one station to another; for Beirut the abrupt change is localized to 1910, whereas it is 1922 for Marakesh and 1865 for

Table 2. *The Beginning of the Annual and Seasonal Abrupt Change for Six Southern Mediterranean Stations*

Station	Annual	Winter	Spring	Summer	Autumn
Markesh	1922 (+)		1922(+)	1922(+)	1976(+)
	1976(+)		1976(+)	1979(+)	
Alger	1865(+)	1872(+)	1967(+)	1866(+)	1955(+)
	1967(+)		1856(−)	1967(+)	
Tripoli		1955(+)	1957(+)	1965(+)	
		1982(+)		1983(+)	
Alexandria	1962(−)	1961(−)	1958(+)		1962(−)
Amman	1955(−)	1955(−)	1935(+)	1927(+)	1962(−)
		1975(+)	1973(+)	1976(+)	
			1958(−)		
Beirut	1910(+)	1918(+)	1911(+)	1911(+)	

(+) Warming
(−) Cooling

Alger. Also, another abrupt change towards warming occurs at Marakesh in 1976, and for Alger in 1967. On the other hand, Alexandria and Amman show a change towards cooling, localized to 1962 for Alexandria, and to 1955 for Amman.

Significant abrupt climatic changes in seasonal surface temperatures are shown in Fig. 3a, 3b and 3c. In the winter season, a change towards warming is shown for Alger (1872), Tripoli (1955, 1982), Amman (1975) and Beirut (1918). While an abrupt change towards cooling is localized in Alexandria in 1961, and in Amman in 1955. In spring an abrupt change towards warming is found for Marakesh (1922), Alger (1967), Tripoli (1957), Alexandria (1958),

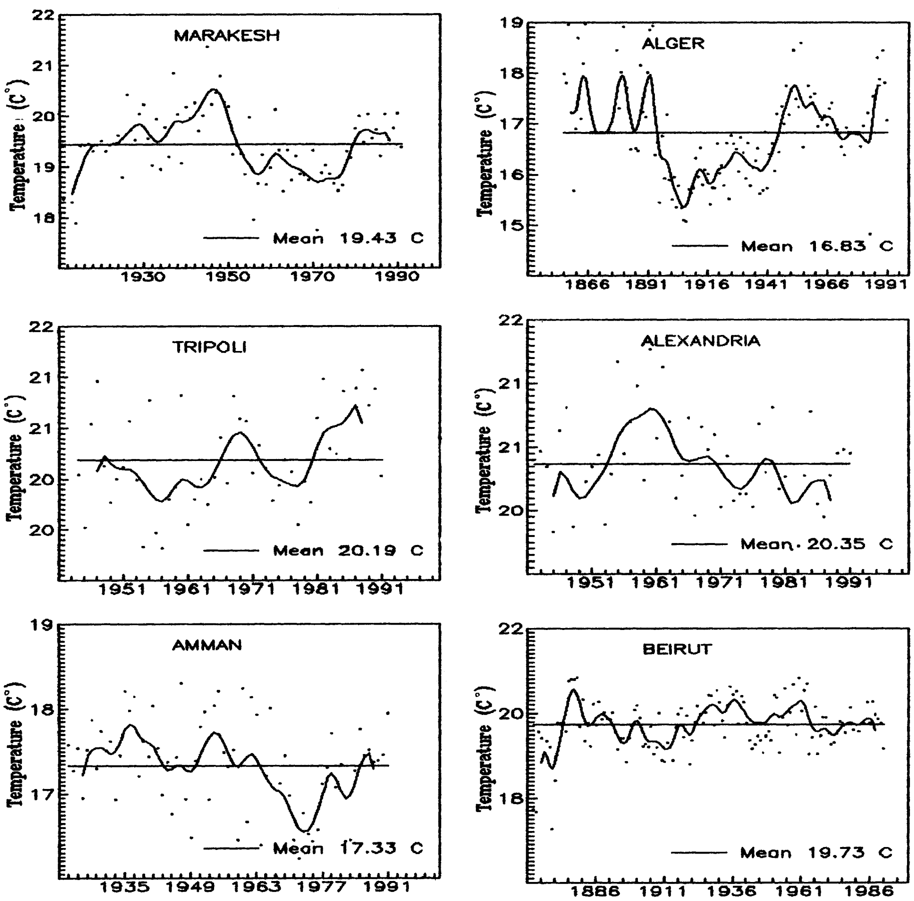

Fig. 4. The fluctuations of the annual temperatures at six Mediterranean stations

Table 3. *Autocorrelation Coefficients for Annual and Seasonal Values of Temperature for Time Lags 1, 2, and 3 Years*

Station	Time lag	Annual	Winter	Spring	Summer	Autumn
Marakesh	1	0.43**	−0.02	0.07	0.41**	0.26*
	2	0.44**	0.01	0.29*	0.40**	0.21*
	3	0.47**	0.21*	0.25*	0.30*	0.16
Alger	1	0.58**	0.27*	0.47**	0.38**	0.33**
	2	0.51**	0.20*	0.45**	0.35**	0.31*
	3	0.43**	0.28*	0.39**	0.32*	0.23*
Tripoli	1	0.24*	0.09	0.33**	0.64**	0.38**
	2	0.09	0.06	0.26*	0.52**	0.25*
	3	0.19	0.09	0.11	0.49**	0.42**
Alexandria	1	0.16	0.25*	0.21*	0.58**	0.27*
	2	0.06	0.19	0.07	0.69**	0.27*
	3	0.08	0.22*	0.09	0.56**	0.36**
Amman	1	0.17	−0.11	0.00	0.38**	0.11
	2	0.08	−0.05	−0.03	0.24*	0.27*
	3	0.22*	0.10	0.16	0.35**	0.26*
Beirut	1	0.15	0.01	0.32*	0.52**	0.23*
	2	−0.09	−0.02	0.12	0.33**	0.22*
	3	0.02	−0.13	0.14	0.44**	0.25*

* Significant at level 95%
** Significant at level 99%

Amman (1935) and for Beirut (1911). Also, another abrupt change towards warming occurs at Marakesh in 1976, and at Amman at 1973. A change towards cooling occurs at Alger (1856), and for Amman (1958). In summer a climatic change towards warming occurs at Marakesh (1922, 1979), Alger (1866, 1967), Tripoli (1965, 1983), Amman (1927, 1976), and at Beirut (1911). In autumn an abrupt climatic change towards warming occurs at Marakesh (1970), and Alger (1955). Alexandria and Amman both show an abrupt change towards cooling at 1962. Table 2 summerizes the above results and shows the beginning of the annual and seasonal abrupt warming (positive sign) or cooling (negative sign) events for all stations.

3.3 Persistence

To study the properties of frequency variation and to estimate the degree of linearity, the first order linear Markov persistence is used. The autocorrelation coefficients r_1, r_2, and r_3 have been calculated for all the temperature time series (Mitchell et al., 1966). The first non-random variable which has to be considered is the persistence. Gilman et al. (1963) suggested a method for finding the persistence of the first order linear Markov process which has the property $r_n = (r_1)^n$. The occurrence of persistence is considered after the satisfaction of the relations $r_2 = r_1^2$ and $r_3 = r_1^3$.

Table 2 lists the autocorrelation coefficients for annual and seasonal values of surface air temperature for the time lags 1, 2, and 3 and for the 95% and 99% significance levels. The annual and most of the seasonal values (r_1) are positive, indicating low frequency variations and presence of positive serial correlation at small lags. In the winter season, non-significant negative values for Marakesh and Amman indicate the presence of high frequency oscillations in these time series, or a type of random process.

The annual surface temperature data show significant persistence at the 95% level at Tripoli and at the 99% level at Marakesh and Alger, however, persistence is not significant at the other stations. The values of r_2 and r_3 for all the stations are greater than r_1^2 and r_1^3 respectively, with the exception of Beirut. This shows that the persistence at these stations is a type of Markov linear process, whilst in Beirut the persistence is not linear.

With respect to seasonal values of surface temperature, it is found that the summer has the highest persistence with a value at the 99% signif-

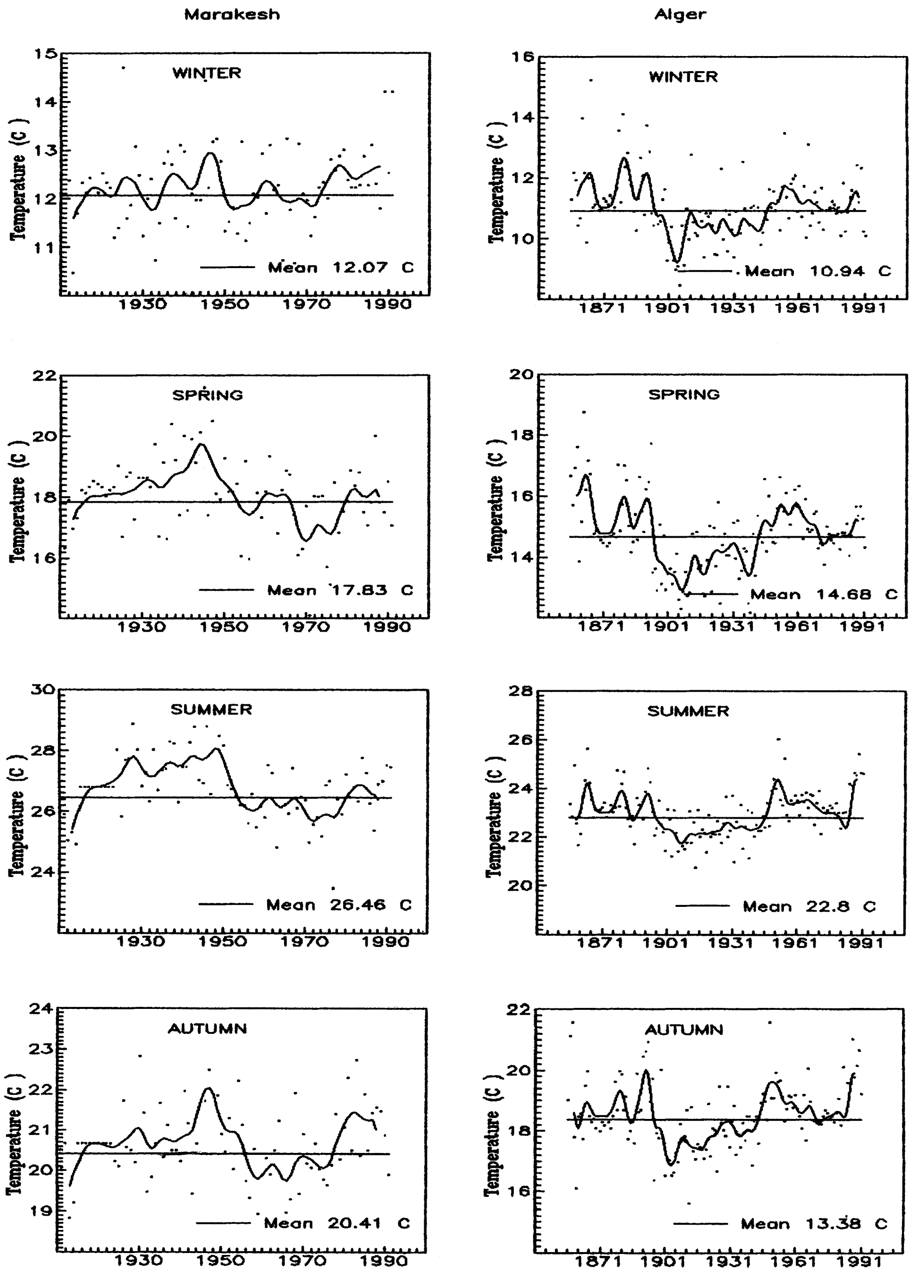

Fig. 5a. The fluctuations of the seasonal temperatures at Marakesh and Alger stations

icance level for all stations. Also, autumn has a high persistence which is significant at the 95% level for Marakesh, Alexandria, and Beirut and at the 99% level for Alger and Tripoli. However, persistence is not significant for Amman. In spring, persistence is significant at the 99% level for Alger and Tripoli and at the 95% level for Alexandria and Beirut but it is not significant for Marakesh and Amman. Values of r_1 are quite low in winter and non-significant with the exception of Alger and Alexandria. Therefore, in the winter season there is no statistical indication of persistence. In comparison, the summer and autumn time series, like the annual series, exhibit a linear type of persistence at all stations.

3.4 Fluctuations in Temperature

To study the climatic fluctuations we examine smoothed time series. We have used asymmet-

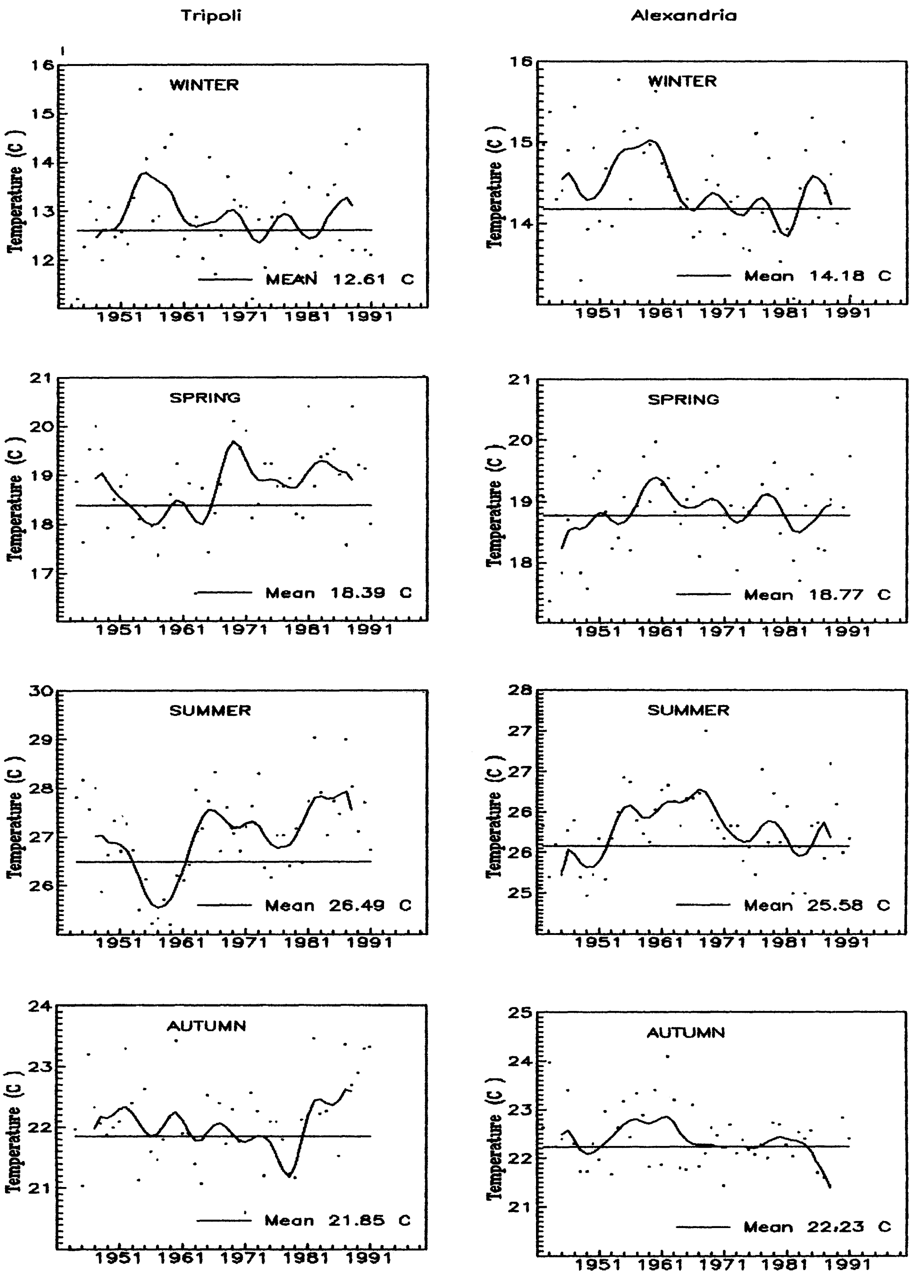

Fig. 5b. The fluctuations of the seasonal temperatures at Tripoli and Alexandria stations

rical moving averages in which the weighting of successive terms in a series varies asymmetrically both backwards and forwards from a central weight (Mitchell et al., 1966). A Gaussian low-pass filter is used to suppress the high frequency oscillations leaving only lower frequency waves in the series. In the filtered series the trend is not linear but oscillatory, consisting of periods of more than 10 years in duration.

3.4.1 Fluctuations of Annual Temperatures

Most of the annual temperatures, have been above the average during the last 25 years, beginning in 1976 for all stations, except Alexandria and Beirut (Fig. 4). An important warming began at Marakesh, Alger, and Beirut around 1910. The annual temperature time series also exhibited warming around 1970, but this

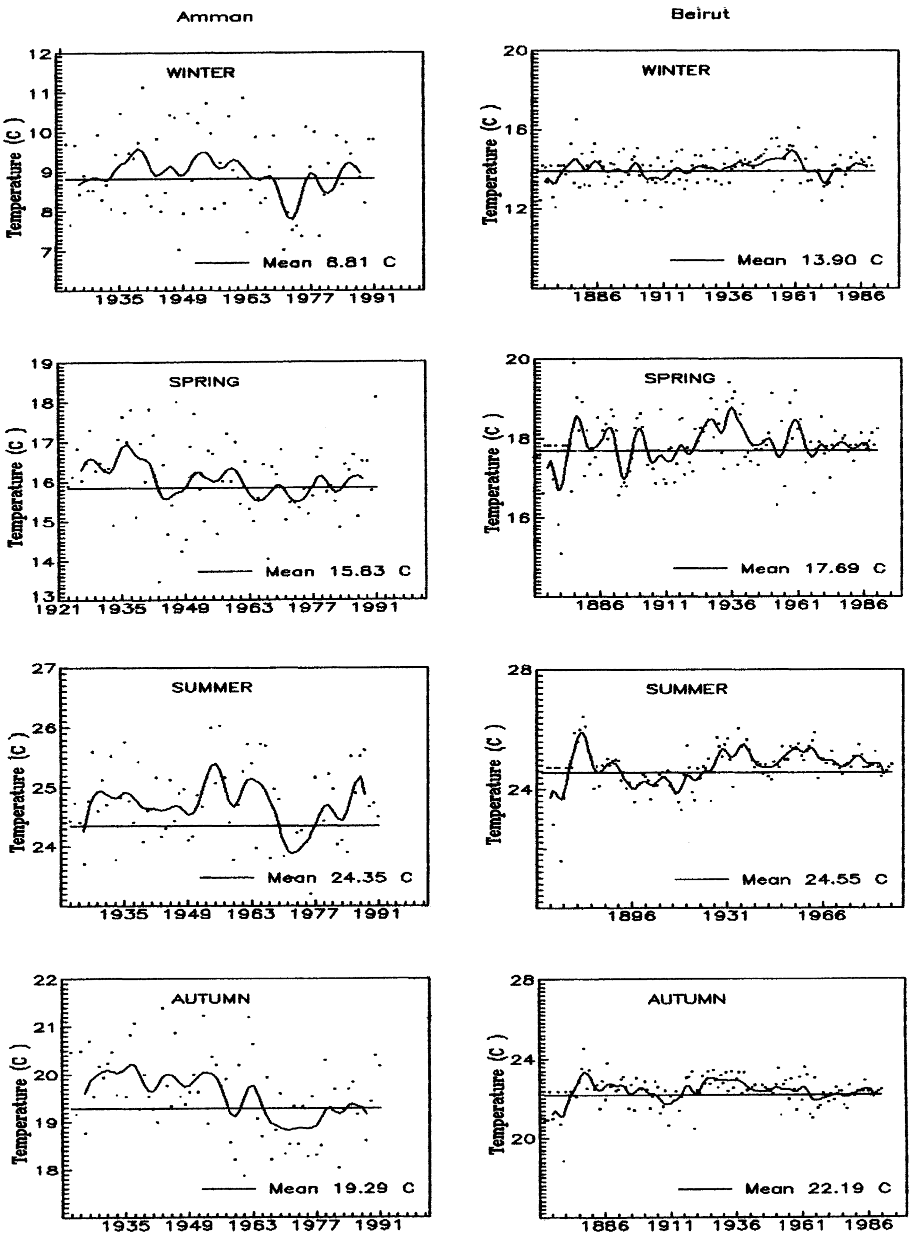

Fig. 5c. The fluctuations of the seasonal temperatures at Amman and Beirut stations

was not uniform, continuous, or of the same order for all areas under investigation, as in agreement with Folland et al. (1990). However, some distinct decreases in temperature were also observed. Cooling was more intense in Marakesh in the 1940s till the mid 1950s. In Alger cooling began at the end of the last century, and in Amman in the 1960s.

The important warming which began around 1910 has also been found by other researchers and in other areas: Dettwiller (1970), Arseni (1973), Metaxas (1974), Petit-Renaud (1976), Escourrou (1978), Kelly et al. (1982), Wigley and Farmer (1982), Colacino and Rovelli (1983), Jones and Kelly (1983), Repapis (1984), Balzano and Todaro (1985), Maheras (1989a), and Arseni and Maheras (1991). It seems that this warm period has not only been observed in the Mediterranean area, but also in the northern hemisphere, and in certain other areas or at other stations, with some exceptions (Maheras, 1989a). Its duration has varied from place to place, however, this warm period shows an earlier start in higher latitudes than in lower latitudes (Schönwiese, 1978; Maheras, 1989a).

3.4.2 Fluctuations of Seasonal Temperatures

Fluctuations in seasonal temperatures at six Mediterranean stations are shown in Fig. 5a, 5b, and 5c. For the winter season, fluctuations around the mean value are shown for Marakesh, Tripoli, Amman and Beirut. There is a cooling of about 2.5 °C at Alger in the period 1891–1910 and of about 1 °C at Alexandria in the period 1960–1966. Also, there is a gradual warming at Alger from around 1910. Generally, it is found that the longer term fluctuations of winter temperatures are similar, although with some differences from the annual series and consequently they contribute only little to the formation of the longer term annual fluctuations. This fact has also been found by other researchers (Sawyer, 1983; Maheras 1989a; Arseni and Maheras, 1991). The variability of winter temperatures from year to year is quite large.

Spring temperature fluctuations follow those of the annual temperatures, except for Alexandria and Amman. It should be noted that after 1941 spring temperatures in Amman fluctuated around the mean value whilst temperatures at Alexandria were higher than the mean value.

It is also notable that summer temperatures at Alexandria, Amman, and Tripoli after 1962 were higher than the mean values. There is a gradual increase at Marakesh in the period 1910–1940 and from the beginning of 1910 until the end of the period, at Beirut and Alger. Summer temperatures also showed a distinct increase, in the order of 2.0 °C, at Alger (1941–1951) and Beirut (1868–1876). On the other hand, a distinct decrease was observed, in the order 2.0 °C, at Marakesh (1947–1957) and of 1.5 °C, at Amman (1962–1972).

The autumn series are similar to the corresponding annual series. The only major difference is related to the amplitude of the fluctuations, which is in agreement with the results of other researchers, for example Arseni and Maheras (1991).

4. Conclusion

By examining the annual temperature times series it was shown that a significant abrupt climatic change was observed at all stations except for Tripoli. Warming episodes occur at Marakesh in 1922, and in 1976, at Alger in 1865, and in 1967, and at Beirut in 1910. On the other hand, changes towards cooling took place at Alexandria in 1962, and at Amman in 1955. For all seasons most of the stations showed evidence of abrupt climatic changes. These results are in agreement with Arseni and Maheras (1991) who found an abrupt climatic change toward warming for three stations in the Mediterranean (Marseille 1942, Rome 1893, and Jerusalem 1920). However, Goossens and Berger's (1986) study of climatic variations over the northern hemisphere and Europe does not show any definite behavior towards a warming or a cooling over the period for which we have climatological records. The question that arises from our results and from other studies is: Why do most of the stations in the Mediterranean not show abrupt climatic changes in the same years? In a future paper we will study this important point, to try to find an answer to our question.

The study of persistence shows it is significant for annual temperatures in Marakesh, Alger and Tripoli (Western Mediteranean). It should be mentioned that persistence was not always linear. For seasonal temperatures, summer and autumn exhibited the highest levels of persistence at all stations. This phenomenon appears to be directly related to the influence of the sea, due to the low frequency of cyclonic systems, as found by Arseni and Maheras (1991). In addition, the normal barometric fields (Maheras, 1980; 1989b) favoring sea breezes in the central and western Mediterranean area occur in summer with the highest frequencies. However, for the eastern Mediterranean stations it seems that the direction and high frequency of the etsian winds also play a significant role (Maheras, 1980; Arseni, 1984). This is in agreement with the views of other researchers concerning the role of the sea in temperature persistence for Athens (Metaxas, 1974) and Nicosia (Maheras and Arseni, 1988).

Regarding the fluctuations in annual temperature, the results show that there was a warm period that began in 1910, in agreement with the warming period for the whole global land surface. Another warm period began in 1970 at all stations, but it was not continuous or of the same form as the global phenomenon. During the study period some temperatures also decreased. Recent warming has been observed during the 2nd or 3rd decade of this century at most stations. This could be attributed to human activities (i.e. increased concentrations of CO_2). For the seasonal temperatures it appears that in winter most stations are around the mean values, while in summer the last three decades have been distinctly higher than the mean values.

Acknowledgements

The authors are very grateful to their colleagues in the Astronomy and Meteorology Department, Cairo University for their helpful advise. The thoughtful comments and suggestions of the external reviewers are also gratefully acknowledged.

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