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Meteorological analysis of a severe drought in Greece

A. LIAKATAS and A. NIANIOS

Hellenic National Meteorological Service, Athens, Greece

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सार — यूनान में, सन् 1977 में शीत व बसन्त ऋतु के दौरान पड़े भीषण सूखे का विवेचन किया गया है। सूखे के विशिष्ट लक्षणों वाले मौसम वैज्ञानिक प्राचलों के व्यवहार का उस समय ऊपरी वायुमण्डल में बड़े पैमाने पर विद्यमान वायुसंहति के साथ अध्ययन किया गया है।

पवन, ताप तथा आर्द्रता के आंकड़ों का प्रयोग करते हुए यह दिखाया गया है कि विद्यमान मेघों की विनाशकारी अधोगामी गति ने वृष्टिपात में बाधा डाली। ऊर्जा तथा जल के सन्तुलन में परिवर्तन के कारण जैसे ही सूखा पड़ा, वृष्टिपात की संभावना और कम हो गई।

अन्ततः सूखे को उत्पन्न करने वाली मौसम वैज्ञानिक विसंगतियों को स्पष्ट करने का प्रयास किया गया है।

ABSTRACT. The severe drought in Greece during the winter and spring 1977 is described. The behaviour of drought-characteristic meteorological parameters is then studied along with the large-scale air mass in the upper atmosphere.

Using wind, temperature and humidity data, it is shown that the prevailed cloud-destructive downward movements prevented precipitation. The probability for precipitation was further reduced once the drought had been established, due to changes in energy and water balances.

Finally an explanation of the drought-inducing meteorological anomalies is attempted.

1. Introduction

For meteorologists, weather anomalies are in fact a "normal" situation. Long climatological deviations, however, may have enormous impacts on national economies. According to the Congress of USDA (1964), it is drought that most severely reduces agricultural yield, though drought may mean something different for agronomists, hydrologists or economists, as indicated by the number of its definitions (Palmer 1964).

A typical analysis considers drought intensity as a function of cumulative differences between actual and required precipitation. The required precipitation depends on the previous rainfall and evapotranspiration, as well as the moisture recharge and run-off, that are climatically sufficient at a place, at a time.

In Greece, the most recent very severe drought occurred between December 1976 and May 1977. The characteristics of this climatic anomaly will be described, and an investigation of the feasibility to explain the onset and establishment of the drought will be attempted.

2. Anomalous meteorological parameters

In Fig. 1, the monthly distribution of the actual normal precipitation ratio is presented. For the whole drought period, this ratio was generally smaller than unity; there were also rainless months for large areas. March gave and mainland, particularly the east part, received the least rainfall.

Apart from the actual, the average precipitation yield per day, *i.e.*, the ratio (P/N) of the total precipitation to the number of rainy days that serves as a precipitation-efficiency index, was less than normal, as it is shown in Fig. 2 for four representative stations. January and February were the common for all stations months with the greatest negative deviation from normal P/N; negative values, however, were observed in up to six months in central Greece.

P/N was found to be linearly related to relative humidity (Namias 1967). The mean 10-daily values of relative humidity and efficient precipitation at Aliartos, when compared with their normal values, show the unusual dryness of the studied period (Fig. 3). This is also shown by the order, among the 12 driest years, of the cumulative precipitation in the first five months of the year for the three Greek stations with the longest records (Table 1). 1977 was not only the driest year but its precipitation was lower, by 1/3 compared with the second driest year. Probability analysis showed that cumulative rainfall equal or smaller than that of 1977 could reoccur every 21 years in Salonika, 152 years in Athens and 270 years in Aliartos.

The behaviour of other meteorological parameters becomes clear through Table 2. Screen air temperature (T) and its difference from the dew point temperature

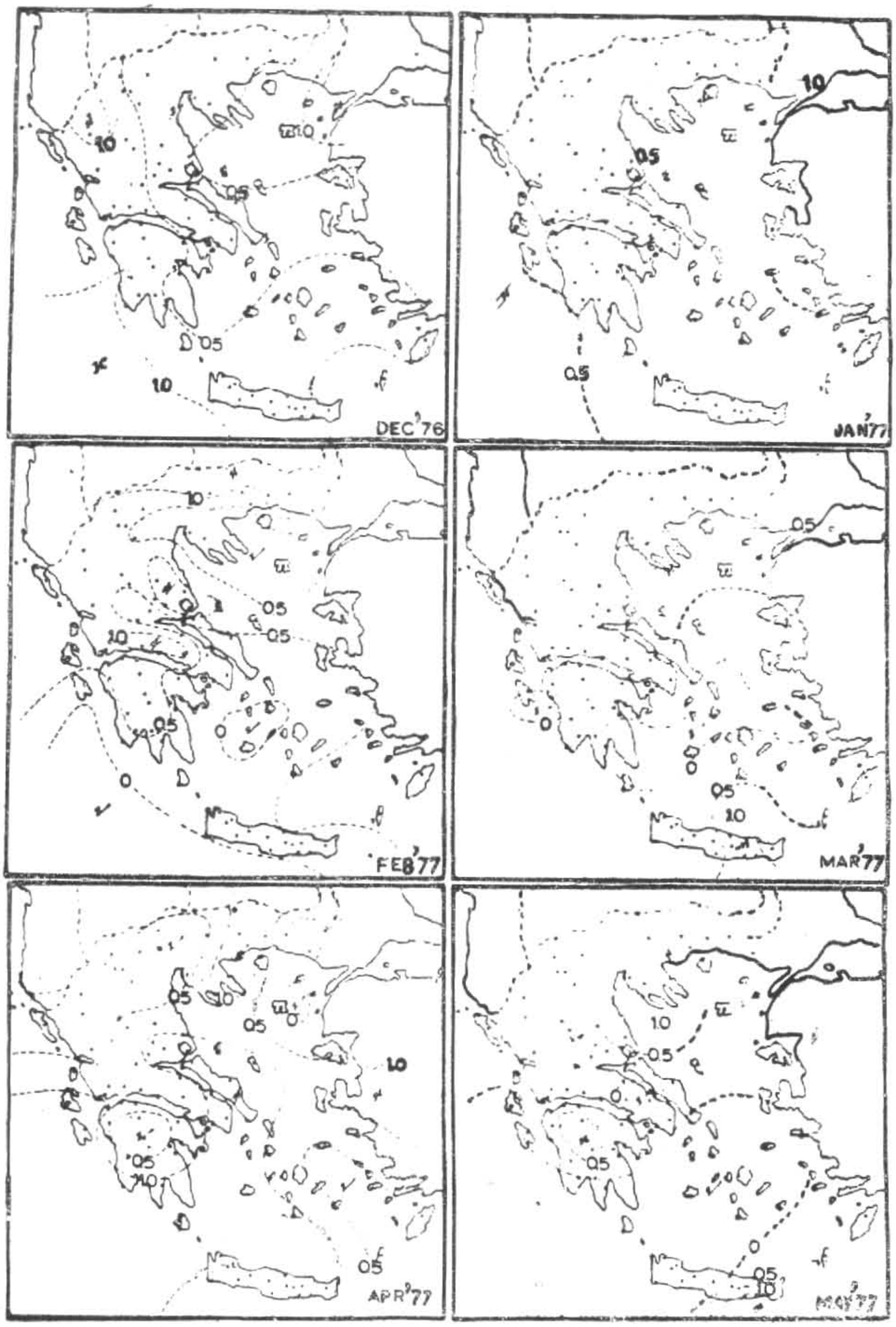

Fig. 1. Monthly distributions of the actual/normal precipitation ratio between December 1976 and May 1977

(T—Td) were higher than normal by 0.6 °C, indicating a warmer but equally humid atmosphere, on average. Wind velocity (V) had both negative and positive deviations from normal in places; V was characteristically weaker than normal by at least 1.5 B. On average, sunshine duration (S.D.) was by 11 % longer, class-A pan evaporation (E) was up to 56 % higher, whereas P/E was by 50 % smaller than normal. (ET—P), the difference of precipitation from the potential evapotranspiration estimated for winter cerials (Liakats 1976), was on average 1.6 mm per day, approximately double the corresponding mean of the period 1975-1980.

The unusually lower than normal soil moisture reduced yields in 1977 (Fig. 4). Yield reduction becomes even more obvious in a time series plotting of soft wheat yield and seasonal rainfall (Fig. 5), where the development trend was statistically removed (Crow *et al.* 1971).

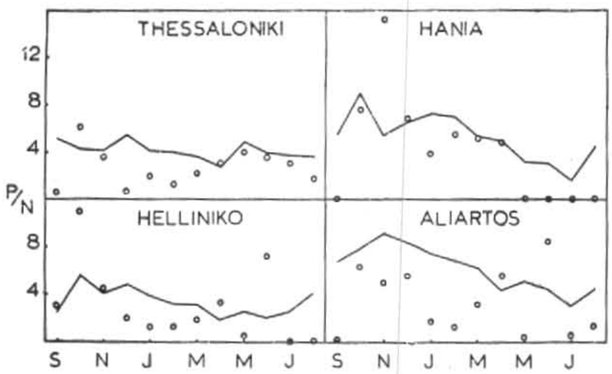

Fig. 2. 1976-1977 values (o) and normal values (—) of efficient precipitation (*P/N*) for four stations

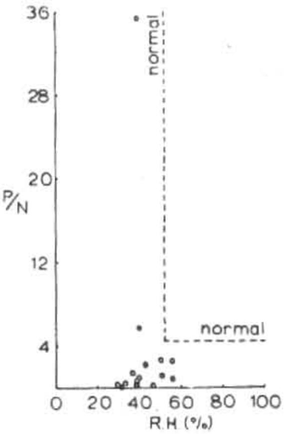

Fig. 3. Efficient precipitation (*P/N*) against mean 10-daily values of relative humidity at Aliartos during the drought, compared with the corresponding normal values

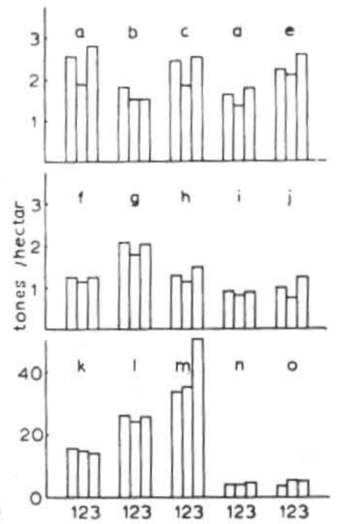

Fig. 4. Comparison of 1976 (1) 1977 (2) and 1978 (3) crop yields (a : wheat, b: rye, c: barley, d : oat, e: cotton, f: tobaco, g: bean h : faba beans, i : chick peas, j: lentils, k: potatoes, l: melons, m: tomatoes, n : maize and o: rice)

TABLE 1

Cumulative (Jan–May) precipitation in the 12 driest years of three Greek stations

Thessaloniki (Period : 1925-1980)		Aliartos (Period : 1911-1980)		Athens (Observatory) (Period : 1895-1980)	
1977 :	88.8	1977 :	84.5	1977 :	50.8
1930 :	108.7	1958 :	137.0	1947 :	93.7
1945 :	110.1	1979 :	202.1	1959 :	97.7
1948 :	110.9	1945 :	219.0	1926 :	98.4
1957 :	112.7	1969 :	220.0	1941 :	112.1
1941 :	113.4	1922 :	223.0	1970 :	120.2
1947 :	116.8	1973 :	225.0	1913 :	121.6
1932 :	120.4	1967 :	225.0	1896 :	122.9
1975 :	127.8	1947 :	233.0	1929 :	125.8
1933 :	130.3	1917 :	242.0	1962 :	126.2
1961 :	130.8	1941 :	248.0	1946 :	126.5
1958 :	131.0	1970 :	251.0	1957 :	128.4

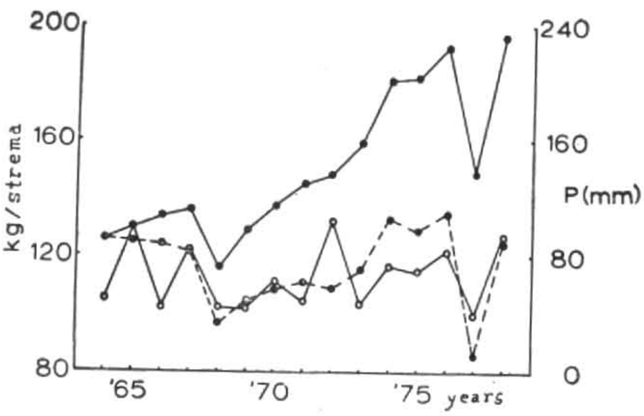

Fig. 5. Time distribution of actual (●——●) and trend-free (●— —●) soft wheat production against seasonal (March–May) precipitation (o——o)

Rainfall and temperature anomalies will now be considered in relation to the characteristics of the atmospheric airstreams that prevailed during the period of drought.

3. Relative patterns of atmospheric circulation

Apart from the normal seasonal variations in intensity and direction of upper airstreams describing

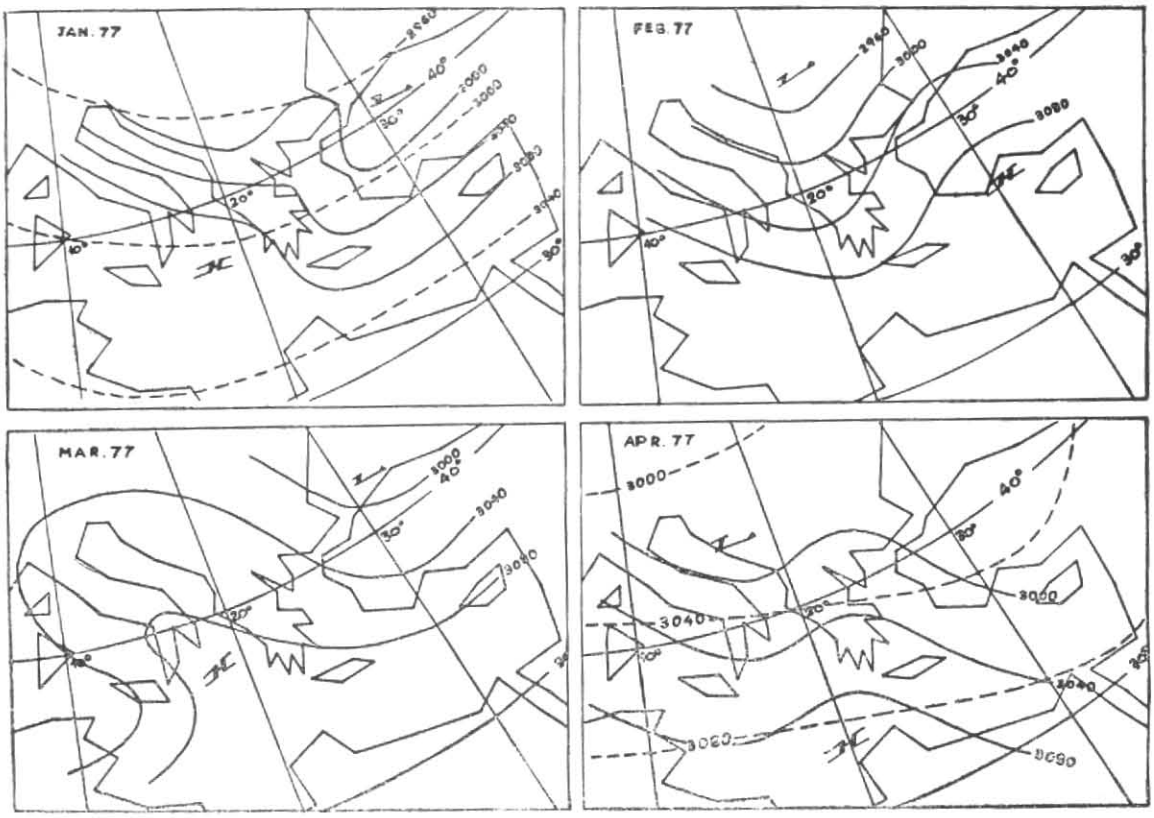

Fig. 6. Monthly mean (— — —), between Jan and Apr 1977 and corresponding long-term average (———) 700 mb atmospheric circulations over East Mediterranean

TABLE 2

Mean for the drought period values of temperature (*T*), its difference from dew point temperature (*T-Td*), wind velocity in Beaufort (*V*) & their deviations (△) from corresponding normals, sunshine duration (SD), precipitation (*p*), evaporation (*E*), difference between evapotranspiration and precipitation (*ET-P*) and their ratios (*R*) over corresponding normals (bars refer to long-term averages)

Station (Meteorological)	T	$\triangle T$	$T\text{-}T_d$	$\triangle(T\text{-}T_d)$	V	$\triangle V$	SD	RSD	P	RP	E	RE	$\bar{P}/\bar{E}$	P/E	$ET\text{-}P$	$R(ET\text{-}P)$
1 KOMOTINI	11.6	1.3	5.6	0.2	1.90	—0.24	4.8	1.09	1.28	0.77	2.21	0.99	0.74	0.58	1.07	1.13
2 SERRES	12.0	1.2	6.5	0.4	1.38	—0.42	5.1	1.12	0.94	0.73	2.74	1.24	0.58	0.34	0.76	2.16
3 THESSALONIKI	12.1	1.1	6.6	1.3	1.70	0.06	4.9	1.11	0.49	0.41	3.47	1.22	0.42	0.14	2.35	1.77
4 ARTA	14.1	0.8	6.8	0.1	1.29	—1.89	5.0	0.98	1.82	0.57	2.98*	1.00	1.07*	0.61	0.28	3.94
5 LARISSA	12.3	1.1	7.0	1.5	1.53	0.47	5.7	1.19	0.68	0.63	4.49	1.56	0.38	0.15	1.54	1.49
6 ALIARTOS	13.7	1.0	6.9	0.9	1.56		5.5	1.19	0.47	0.26	3.00	1.17	0.71	0.16	2.18	2.41
7 ADRAVIDA	14.1	—0.7	5.8	—0.7	0.95		5.8	1.08	0.88	0.43	3.00	1.14	0.78	0.29	0.71	1.43
8 KORINTHOS	15.3	1.4	8.5	2.1	2.00	0.06	6.0	1.18	0.37	0.34	4.56*	0.95	0.23*	0.08	5.81*	1.37
9 KALAMATA	12.9	—0.8	3.4	—1.8	2.37	0.95	6.0	1.10	0.97	0.39	3.14	0.99	0.79	0.31	1.87	2.76
10 HANIA	15.4	0.5	6.0	—0.3	0.58	—1.50	5.8	1.11	0.80	0.40	2.81	0.97	0.69	0.29	1.70	2.45
11 TIBAKI	15.6	0.6	7.7	2.4	2.80		6.7	1.16	0.41	0.30	4.32	1.01	0.32	0.09	3.34	1.59
12 IERAPETRA	16.0	0.2	5.9	0.6	2.73	0.29	6.8	1.12	0.88	0.52	4.22	0.93	0.37	0.21	2.04	1.24
Mean	13.8	0.6	6.4	0.6			5.7	1.11	0.83	0.48						1.98

*Atmometer Piche

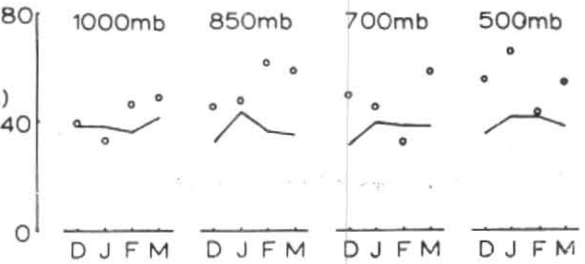

Fig. 7. Monthly variation of northwest winds distribution at 1000, 850, 700 and 500 mb during drought (o) compared with normal (———)

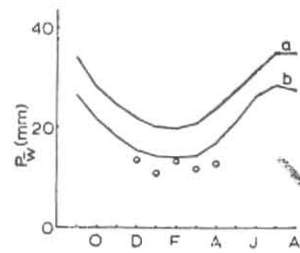

Fig. 9. Monthly precipitable water (Pw) up to 500 mb over Helliniko during drought (o) compared with corresponding long-term values for the spot (a) and the north hemisphere (b)

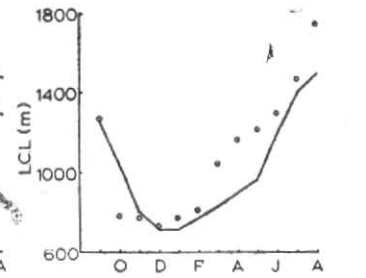

Fig. 10. 1976-1977 values of water vapour condensation level (L. C. L.) over Helliniko (o) compared with the corresponding normals (———)

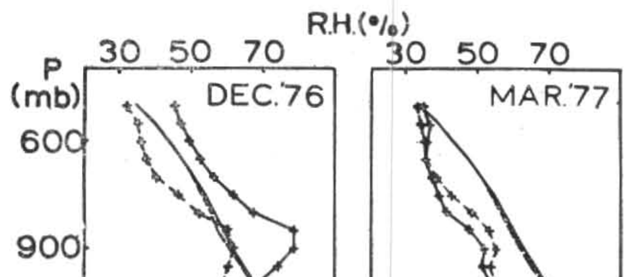

Fig. 8. 1200 GMT temperature (——) and relative humidity (+——+) profiles during drought compared with corresponding normal (— — and +— - - +) over Helliniko

corresponding weather variations, there are often abnormal, non-seasonal variations (anomalies), causing weather irregularities that come to light by comparing the mean for a certain period situation with the corresponding long-term (normal) average.

The mean, between January and April 1977 and the corresponding long-term average 700 mb atmospheric circulations, determining cloud movement, are shown in Fig. 6. Generally, the 1977 winds diverted from the usual westerlies becoming northwest. Fig. 7 confirms the northwesterly component of the air current also for other isobaric levels. The frequencies of the winds blowing between 280° and 360° at 1000, 850, 700 and 500 mb over Helliniko station in the period December 1976 to March 1977 were generally higher than the long-term (1960 - 1976) frequencies.

The more frequent northwesterlies in 1977, associated with precipitation-preventive downward movements, indicate that the net cumulative effect of atmospheric disturbances with alternating active and non-active sectors and rainy & non-rainy spells may have yielded drought.

The effect of the abnormal air flow on the structure of the upper atmosphere becomes obvious from the monthly mean 1200 GMT values of temperature and relative humidity over Helliniko (Fig. 8). The subsiding winds, apart from atmospheric stability, cause pseudo-adiabatic compression and thus, heating. This, along with the differentiated distribution of available energy above the relatively dry ground (Section 4), resulted on average in warmer than ususally for the period, atmosphere. The deviation of temperature from normal was maximum in February. The corresponding deviation of relative humidity was positive in December & January and it started changing sign in February at a shallow layer to extend from surface to 550 mb in May.

It seems that the relative atmospheric dryness, pronounced in all spring months, was also a result of large scale downwards air movements.

The variation of absolute humidity was similar. The humidity contained in an air column can be expressed as precipitable water :

$$P_w = \frac{1}{g} \int_{P_z}^{P_0} r \, dp$$

where r is the mixing ratio (g/kg) and P_0 and P_z are the corresponding pressures (mb) at the bottom and the top of the air column. Monthly P_w up to 500 mb over Helliniko during the drought months, along with its long-term values for the spot only and the north hemisphere as a whole, are given in Fig. 9. Between

December 1976 and April 1977 P_w over Helliniko was smaller than normal by 15% and even smaller than the hemispheric average.

4. Possible reasons

Any attempts to determine possible reasons for the climatic deviations that led to the severe drought of 1977 would phase the fantastic complexity of the behaviour of the atmosphere, characterised by the interdependence of all changes in space and time. External boundary conditions, such as surface temperature and soil moisture, affect atmospheric behaviour by means of received solar and emitted terrestrial radiation and differentiate heat and moisture amounts transferred from ground surface. However, the exact effect of the changing boundary conditions of the atmosphere depends on the characteristics of the atmosphere itself. Therefore, the effect of an anomalous external boundary condition depends on the pattern of the general air flow in the upper atmosphere and the weather.

Assuming that the key in explaining the 1977 drought in Greece was lying in the relatively dry and cloud-destructive northwest air currents—a result of the intensive anticyclone created and established over the west coast—what was the reason for such an unusual synoptic situation ? Explanations of similar cases in the past were attempted by means of the unusual change in the position of a jet-stream (Brochet 1976) or the significant differantiation of the sea temperatures (Tannehill 1947; Ratcliffe 1978).

Tannehill even tried to combine the differentiation and, consequently, the effect of sea temperatures with the solar activity. However, approaches like this are rather doubtful (Burroughs 1986). Deviations from normal are only symptoms, syndroms or phases of some more general anomaly—a link of a chain whose origin is either difficult or impossible to trace.

Searching the processes that preserved drought, once established, seems to be easier. Since an unusually high proportion of the available solar energy over dry land is dissipated as heat flow to the soil and the air, rather than as latent heat for evaporation, there is a tendency for a drought to persist after its establishment. The extra heating increases the atmospheric moisture deficit and at the same time, the need for rainfall, while decreasing the probability of rainfall (Namias 1966).

Other factors also diminish the probability of rainfall after a prolonged period of anomalously warm and dry weather. Mainly the low relative humidity (Fig. 8) was responsible for the higher than normal water vapour condensation levels (L.C.L.) over Helliniko, due to mechanical or thermal convection during the drought months (Fig. 10). The higher than normal condensation levels restricted the rainfall-favouring processes. Even if condensation did happen the thicker layer of dry air from surface to cloud base caused higher than normal evaporation of rainfall before it reached ground. These rainfall-preventive factors seem to have been more efficient in spring, when L.C.L. was above 1000 m, approximately 250 m higher than normal.

The drought-preserving factors can change or stop existing at any time. Drought is established and preserved only by means of a continuous repetition of analogous circulation processes (Maller 1983).

5. Conclusions

The above results show that the drought in winter-spring 1977 was for Greece the most severe in the century. The circulation pattern during this period was characterized by more northerly than normal winds. This anomaly was combined with an anticyclonic flow, downward movements, adiabatic heating and dryness in the atmosphere.

After drought establishment the differentiation of energy and water balances led to cloud-destructive processes and reduced the probability whereas increased the necessity for rainfall, thus intensifying the problem.

The complexity of atmospheric processes restricts searching for causes of drought only in the determination of phase of a long procedure. Though interaction between land, sea and atmosphere may mean the onset of drought, the mechanisms involved are not always understandable and tracing of "the starting point" may require searching back for more than a season. Drought predictability, therefore, might become better by relating mean weather patterns space or time-wise.

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