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A Contribution to the Study of the Extreme Heatwave over the South Balkans in July 1987

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With 8 Figures

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Summary

In this paper, an attempt is made to study the atmospheric circulation, which caused the extremely hot weather in the Balkans and south Italy during the time period from 19 to 27 July 1987. Also, based on some temperature parameters and Thom's discomfort index, the weather conditions of that time period are discussed. These conditions can be characterized as extremely discomfortable for the people, animals and even plants for many hours every day, resulting in the loss of more than 1,500 lives. Finally an effort has being made to ascertain whether the phenomenon was unprecedented in harshness and duration for Greece.

1. Introduction

Air temperatures that exceed 40 °C or even 45 °C do not constitute an unusual fact for Greece. If we run through the archives of the Hellenic National Meteorological Service, we can find many cases with such high temperatures, which nevertheless did not last for many days. Such a characteristic case occurred on the 10th of July 1977 where the temperatures in the county of Attica and especially at Elefsina meteorological station (WMO No. 16718) and Tatoi (WMO No. 16715) rose to a maximum of 48 °C, while the maximum temperature on those same stations on the 9th and 11th of July was approximately 12 °C less.

In contrast to the above, the time period from 19 to 27 July 1987, portrayed high temperatures called usually "heatwave". These temperatures were lower than those of older cases, but their duration in days and the daily duration as well were unusual. For 9 successive days (19 to 27 July) the maximum temperature in many stations spread over Greece, rose over 38 °C. The minimum temperatures were also relatively high, and the diurnal temperature range was small. Another characteristic was the fact that the values of the temperatures were kept overall near the values of the maximum temperatures for many hours during the day so that the discomfort conditions for the people, animals, and even plants were elongated for many hours every day with tragic results. One thousand five hundred of the weaker individuals died in Athens and so severe problems occurred at the morques and cemeteries. Also water scarcity appeared in many towns and especially in certain suburbs of Athens. The people were flocking towards the beaches, to relieve some of the extreme discomforts caused by the temperature, but even that did not prove to be a solution, as the temperature of sea water at the shores was also unusual high.

Since the phenomenon, belongs to the atmosphere's synoptic scale circulation, Hellenic National Meteorological Service based upon the successful data received by ECMWF, was able to predict the phenomenon two days in advance (that is from 17 July 1987), thus issuing a special warning. Unfortunately none seemed to realize the scale of weather variations that were about to happen, although the newspapers titled on their front pages the coming "killer heatwave".

2. The Concept of the Heatwave

A strict definition of the term "heatwave" has not been yet precisely given in the literature. Many research meteorologists have given loose definitions for the ward "heatwave", (also mentioned as warm invasion), but those definitions are always given with respect to their own perception, having as a result a big variation on the nature of the defined phenomena. In Greece, there are a few scientists (Mariolopoulos and Carapiperis, 1956; Flocas, 1970; Repapis, 1975; Metaxas and Repapis, 1978) having dealt with warm invasions or large warm advections, terms which sometimes can easily replace the word "heatwave".

A distinction has been done by Metaxas and Kallos (1980) between the concepts of warm invasion or large warm advection and heatwaves giving, at the same time, the criteria to define a heatwave day in Greece. These criteria are:

(a) The maximum temperature in Athens Observatory must be at least 37 °C.

(b) The average daily temperature must be at least 31 °C, at the same station.

(c) The maximum temperature at Larissa meterological station (WMO No. 16648) must be at least 38 °C on this day. These two meteorological stations were used because they are regarded to be representative for the Greek region the Athens Observatory being located in the main residential area and near the sea, and Larissa being a purely continental station, where the heatwave phenomenon is strong and apparent.

In Greece experiences have shown that during the summer season a day can be characterized as a heatwave day if its maximum temperature surpasses the 38 °C, a fact which creates health-hazards to men, animals and plants. In the U.S.A. those limits differ from state to state, so the term heatwave is used only for the summer, while a sudden increase in temperature during any other season of the year is characterized as a warm invasion or a large warm advection.

3. Data and Method Used

To study the synoptic structure and evolution of the atmospheric circulation and its possible centres of action which caused the heatwave, over south Italy and the Balkans a mean chart of 500 hPa height was prepared for the 9 day period, i.e. from 19 to 27 July 1987, and for both the 00 and 12 GMT synoptic observations as distributed regularly via the Global Telecommunication System (GTS). Also the height anomaly field, i.e. its departure from 1949–1973 July's average (published by Deutscher Wetterdienst), and the t (student) test for 0.01 and 0.05 statistical level, have been calculated (Brooks and Carruthers, 1953). The mean field and its anomaly have been analysed manually. Also the relative wind vorticity at 500 hPa and the thermal advection at 850 hPa with the associated mean wind fields were calculated from the ECMWF initialized data. Moreover, vertical velocity at 700 and 500 hPa were calculated from ECMWF's initialized data as well, to show the possible large scale subsidence. To find out the particular characteristics of the heatwave and its effect on the weather of Greece, all the observations from the Greek meteorological stations, especially those of temperature, humidity and wind, were carefully collected from 15 to 28 July 1987. Imageries of the Meterological satellites NOAA 9 and METEOSAT were also analysed.

Since, as known (Reiter, 1975), the subtropical jet stream is the principal atmospheric circulation feature over the region under consideration during summer, its positions for both the 00 and 12 GMT synoptic observations were drawn (if possible). Also, the mean positions of the polar jet stream for the period from 19 to 24 July and from 25 to 27 July 1988 were drawn in order to determine the possible interaction, (Reiter, 1975) between these two main atmospheric jet streams.

Finally by calculating Thom's discomfort index $I_d = 0.4\ (T + T_w) + 4.8$ (T: dry-bulb temperature and T_w: wet bulb temperature in °C) for all synoptic observations during the entire heatwave, it has been possible to establish the number of hours during which the highest discomfort conditions occurred within each day.

3. Analysis and Study of the Atmospheric Circulation During the Heatwave

The tropospheric circulation over northwest Africa, the western Mediterranean, Italy, the south

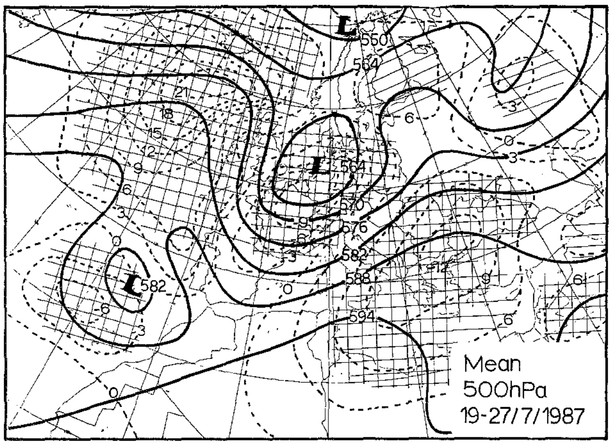

Fig. 1. Mean 500 hPa heights for the time period from 19 to 27 July 1987 and for both 00 and 12 GMT, and their anomalies, e.g. the departures of the 1950–1973's average from this mean. Thick lines are contours drawn in a 6 gpdam interval, dashed lines are anomaly isopleths in a 3 gpdam interval. Horizontally hatched areas include anomaly values significant at 0.05 level of significance and crossed hatched areas include anomaly values significant at 0.01 level of significance

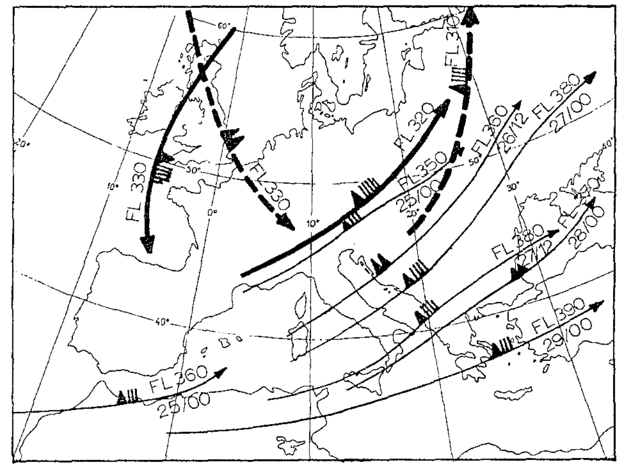

Fig. 2. Positions of main jet streams during the heatwave time period. The thick continuous line is the mean position of the polar jet stream for the time period from 19 to 24 July and the thick dashed line is the mean position of the polar jet stream for the time period from 25 to 27 July 1987. Thin continuous lines represent the positions of the subtropical jet stream from 25 to 29 July 1987. Maximum winds are plotted as on the upper air synoptic charts. FL and the following number denote the level of the maximum wind in hundreds of feets, whereas the numbers below them denote day and time.

Balkans and the central Mediterranean remained almost unchanged from 19 to 27 July 1987, when the heatwave was affecting Greece. So the mean circulation of the middle troposphere during the period under consideration as illustrated by the mean chart of the 500 hPa height (Fig. 1) may show satisfactorily the meteorological factors responsible for the creation of the heatwave. This mean chart indicates that a long wave with ridges over central Europe and the north Atlantic and a low between these two ridges dominates the atmospheric circulation.

The question was, whether a feature of the three comprising the long wave appearing on the 500 hPa chart played the most important role in the creation of the heatwave. To decide this, we examined closely the 500 hPa height's anomaly field i.e. the differences of the July's long-term average 500 hPa height values from the mean 500 hPa height values of the time of interest (for both 00 and 12 GMT observations). For the study of such meteorological and climatological topics the anomaly field plays the most important role (Stringer, 1972). This anomaly fields shows that Azores anticyclone has experienced an intensive strengthening and displacement towards the north. Anomaly values in north Atlantic's region overshoot the 210 gpm being mostly statistically significant at the 0.01 level, a fact which indicates that these high values of the anomaly field are due to the steady residence of the same ridge over the region. This centre of action must play the most important role in the creation of the cold advection towards northwest Europe. This cold advection is performed by the strong north-northeasterlies (as the strong anomaly gradient shows at the east part of the system) depicted in Fig. 2 by the earlier mean position (from 19 to 24 July 1987) of the polar jet stream. The extension of the western ridge northeastwards adopting the shape of a meridional blocking results in the setting up of an intense cyclonic circulation of the eastern flank of this ridge (Bjerkness, 1951). Successive maxima of vorticity are created moving south-southwestwards and at the same time cold air masses are advected maintaining the low system in a very active condition being characterized thus as the key system and also generating a strong horizontal temperature gradient. This temperature gradient adopts a NW—SE direction making the thermal wind increase in the lower half of the troposphere resulting in the strengthening of the southwesterly winds in the whole troposphere.

This sort of atmospheric circulation results in

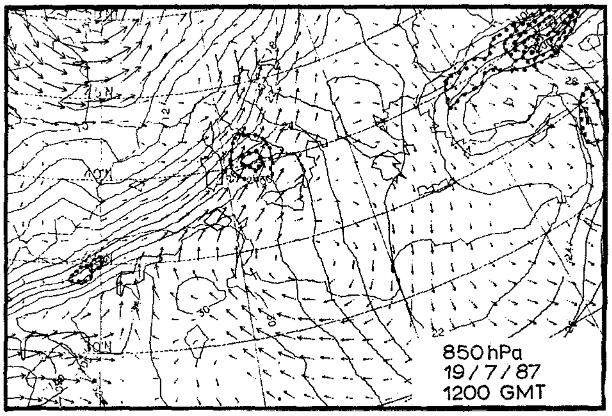

Fig. 3. Objective analysis of 850 hPa temperature and thermal advection fields for 19 July 1978. Continuous lines are isotherms in a 2 °C interval, dotted continuous lines are thermal advection isopleths in a 50×10^{-6} °C sec^{-1} interval, drawn only when the thermal advection values are absolutely greater than 100×10^{-6} °C sec^{-1}. Arrows represent 850 hPa mean wind field. The length of the arrows is proportional to the wind speed. Calculations are based on ECMWF's initialized data

an intensive negative advection of relative vorticity in the middle troposphere and warm advection in the lower one at the region being southeast of the low system.

The warm advection is seen clearly on the 850 hPa chart (Fig. 3), where the air flow coming from southwest, transfers very warm and dry air masses of Sahara origin (Tc) northeastwards. So the region southwest of Rome aquires the greatest values of the warm advection, that is more than 200×10^{-6} °C/sec (Fig. 3). The isotherm labelled 26 °C reaches Sicily on 19 July (Fig. 3) whereas it is over the Balkans on 22 July (not shown).

Thus south Italy and the south and eastern Balkans were covered by Tc air masses of a northwest African origin. This, besides the tropopause height (about 100 hPa) and temperature values (about −70 °C) over Greece it can also be concluded from the high values of the anomaly field (Fig. 1), that they are greater than 120 gpm in the Bulgarian region. These values are mostly significant at the 0.01 level of significance. This means that the anomaly values have a likelihood less than 1 per cent to be random (Brooks and Carruthers, 1953). It also means a continuous increasing of the 500 hPa height in the area from the beginning of the heatwave's appearance as far as its peak are due to the same steadily operating meteorological factors or circulation patterns.

One more indication, that the air masses over Greece and the neighbouring countries have a Saharan origin, is the subtropical jet stream's positions as shown in Fig. 2. It is worth mentioning that before the 25th of July 1987 there didn't exist any indication either on maximum wind chart or in satellite imageries to help us to identify the subtropical jet stream's position. Even the characteristic bands of cirrus clouds accompaning the subtropical jet stream (Reiter, 1975) are completely absent from the satellite imageries. The subtropical jet stream appeared on 25th of July interacting with the polar jet stream over north Italy and north Yugoslavia causing the extremely severe weather occurred there on 25th and 26th of July. On the following day, the subtropical jet stream retrogrates southwards, getting gradually away from the polar jet stream and adopting its usual summer position, i.e. between south Greek mainland and Crete (Prezerakos, 1978, 1985).

Apart from the horizontal intense warm advection the large scale subsidence associated mostly with the negative advection of relative vorticity (the circulation is more anticyclonic on 23 July), appearing over Greece on 500 hPa (Fig. 4), must contribute to this intensive temperature rise (Lyall, 1971, 1979). Over the sea, large scale downward vertical velocities dominate at all levels, whereas over land, being mostly mountainous, overheated by the seasonal prolonged solar radiation, the vertical velocities appear to be slightly (1–3 hPa/h) upward up to 700 hPa associated with absolute instability in the most of the boundary

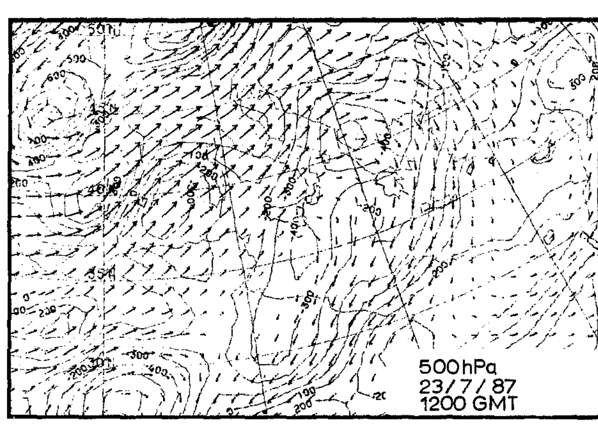

Fig. 4. Objective analysis of 500 hPa relative vorticity for 23rd July 1987/12 GMT. Relative vorticity isopleths are drawn in a 100×10^{-7} sec^{-1} interval. Arrows represent the mean wind field. Calculations based on ECMWF's initialized wind data

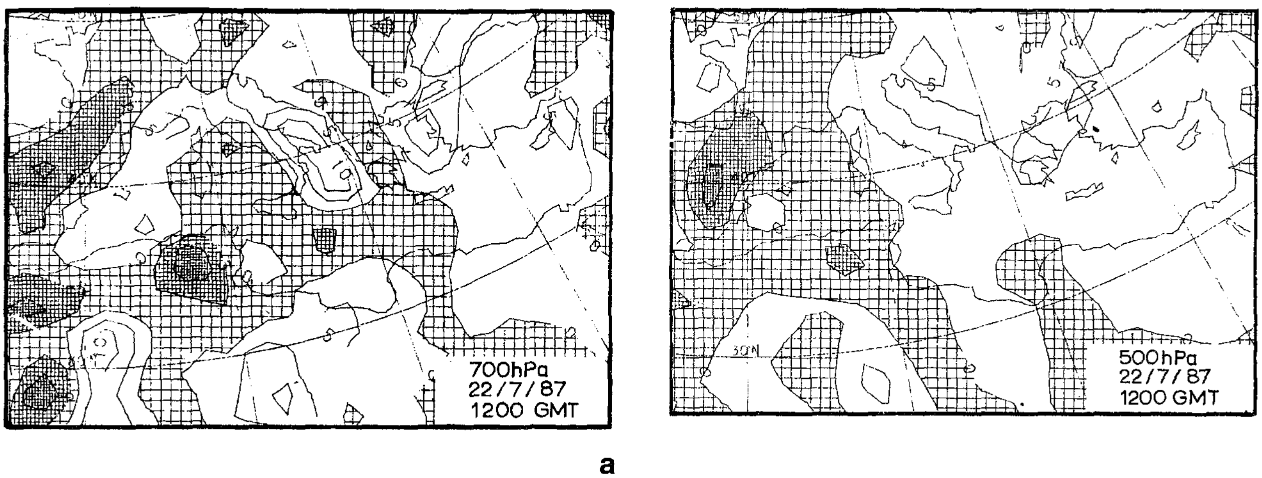

Fig. 5. Objective analysis of vertical velocities (a) at 700 hPa (b) at 500 hPa for 22 July 1987/12 GMT. Isopleths are drawn in a 5 hPa h^{-1} interval. Shaded areas include upward vertical velocities

layer (Fig. 5). Thus the right hand terms of the thermodynamic equation (Wiin Nielsen, 1973):

$$\left(\frac{\partial T}{\partial t}\right)_p = -\vec{V}\cdot\nabla_p T + \omega(\Gamma_a - \Gamma) + \frac{1}{c_p}\frac{\delta q}{\mathrm{d}t} \qquad (1)$$

(T: temperature, $\vec{V}$: wind, t: time, $\omega = \frac{\mathrm{d}p}{\mathrm{d}t}$: vertical velocity, $\Gamma_a = \frac{\partial T}{\partial p}$: adiabatic lapse rate moist or dry depending upon whether the air is saturated, $\Gamma = \frac{\partial T}{\partial p}$: actual lapse rate, c_p: specific heat of moist air at constant pressure, $\frac{\delta q}{dt}$: heat-energy change per unit mass caused by processes other than condensation, ∇_p: horizontal gradient on an isobaric surface) favor the local increase of the temperature at all levels of the lower troposphere. During the night, large scale downward vertical velocities occur at all levels from surface up to 500 hPa (not shown) over Greece, and the neighbouring countries. As a result, even the second of the right hand terms of the Eq. (1) contributes fully to the temperature's increasing, counterbalancing thus the losses by radiation.

These synoptic conditions were kept almost unchanged from 19 to 26 July 1987, resulting in maintaining the surface temperature values at high levels.

On 27th of July the atmospheric circulation became cyclonic at least over north Greece (Fig. 6) with the corresponding cold advection. The value of this cold advection at 850 hPa is greater than 250×10^{-6} °C/sec (not shown). In southern and eastern Greece, as a consequence of this synoptic situation, the wind shear on 500 hPa chart is intensively anticyclonic, resulting in maintaining the large scale subsidence of the tropospheric air over these regions (Fig. 7). As a result the maximum temperature in the cities of the eastern Greek mainland reached their greatest values. The 27th

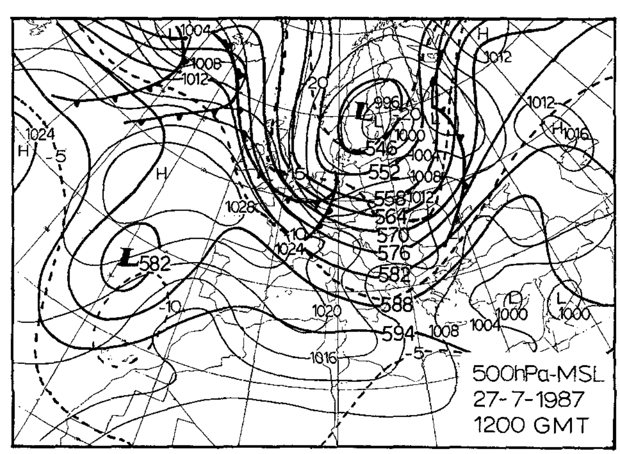

Fig. 6. Subsective analysis of 500 hPa height and temperature fields and also surface pressure fields for 27 July 1987/12 GMT. Thick continuous lines are contours in a 6 gpdam interval, thick dashed lines are isotherms in a 5 °C interval and thin continuous lines are isobars in a 4 hPa interval. Presentation of surface fronts accordingly to WMO's guide on the global data processing system (WMO publication No. 305)

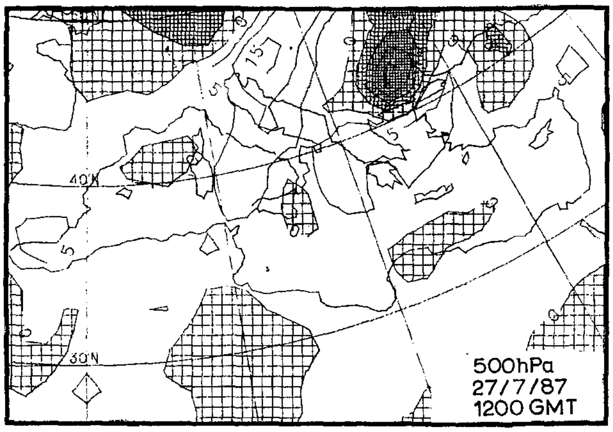

Fig. 7. Same as Fig. 5 (b) but for 27 July 1987

of July was the last day of the heatwave period for eastern continental Greece, because on that day maximum temperatures had already lowered remarkably in northern Greece.

4. The Effects of the Heatwave on the Weather Conditions of Greece

We can easily see from Table 1, that the maximum temperature values at certain meteorological stations located in urban or rural areas of relatively large Greek cities overshot the value of 37 °C and the Metaxas and Kallo's (1980) criteria for defining a heatwave day were fulfilled for almost all days in the time period ranging from 19 to 27 July 1987. These cities, have been selected so as to represent all kinds of Greek local climates. Some of these stations are purely continental e.g. Larissa, Aliartos, some of these partly continental e.g. Nea Philadelphia, being in Athens' region about 20 km from the sea, some of these are coastal stations of the Greek mainland, e.g. Helliniko, Elefsina, Kalamata and Athens Observatory. The last one lies about 5 km from the sea. Finally, there are coastal stations on the Aegean sea islands as Kos, Naxos or on the Ionian sea islands as Corfu and Zakynthos. Heraklion is a coastal meteorological station lying at northern coasts of Crete and Tybaki at southern coasts of the same island. However, many differences referred to the maximum temperature values, appear between these cities of different local climates or geographical characteristics.

It is noteworthing, that some of the meteorological stations of Table 1 lying on the northern coasts of the Aegean sea islands, maintained the air temperature values in low levels far from heatwave's levels. One of these stations, namely Naxos, is the most representative of this category. Naxos recorded maximum temperature's values below 33 °C during all the heatwave's period and so we can say that it was not affected at all by the heatwave. The reasons must be attributed to the composite phenomenon of the sea breeze blowing from the same direction with the estesians which are the prevailing northerly or northeasterly synoptic scale pressure gradient winds, mainly over the Aegean sea (but frequently extending westwards) during the summer (Karapiperis, 1951). Also a fluctuation of maximum temperature values at the stations lying on the southern coasts of the Greek Islands or the Greek mainland are shown in Table 1. To explain this fluctuation we have once more to recourse to the local sea-breeze circulation, which did not appear on some days of the period under consideration. On these days the large scale thermal advection and the air subsidence which were the main factors controlling the air temperature variation over the whole of the Greek region did not allow adequate horizontal temperature gradients to develop between the air over the sea and the air over the land to produce sea breeze or particularly, sea breeze strong enough to predominate the light etesians blowing from the opposite direction. This was the reason why at the Helliniko meteorological station (WMO No. 16716), which is a coastal station in Attica, the sea breeze did not appear to blow at all on 22, 23, and 24 July, whereas a weak sea breeze circulation occurred on 19, 20, 25, and 27 July 1987. The latter fact affects the registration of the temperature (Fig. 8 (a)), which shows peaks on the days when the sea breeze circulation did not occur, whereas it shows a fluctuation around the maximum temperature on days when the sea breeze appeared.

The registration of the relative humidity shows similar results (Fig. 8 (b)). On these latter days, the maximum temperature values kept below the value of 37 °C at the Helliniko meteorological station. We have to mention, that on 27th of July 1987, a day which was for many cities of the eastern Greek mainland the peak of the heatwave period, the maximum temperature at the Helliniko meteorological station, just reached the value of 36 °C, due to the sea breeze blowing, an event

Table 1. *Maximum and Minimum Temperatures Recorded from 19 to 27 July 1987 at Some Greek Meteorological Stations*

Meteorological Stations	No. WMO		Days of July 1987									$\bar{T}max$ $\bar{T}min$
			19	20	21	22	23	24	25	26	27	
Athens Observatory	16714	*Tmax*	36	38	41	42	43	41	41	41	41	32.2
		Tmin	24	25	27	28	28	29	28	27	28	22.9
		D.T.R.	12	13	14	14	15	12	13	14	13	9.3
Nea Philadelphia	16701	*Tmax*	38	41	42	43	42	42	41	43	44	33.2
		Tmin	22	23	26	28	28	28	27	27	26	20.5
		D.T.R.	16	18	16	15	14	14	14	16	18	12.7
Helliniko	16716	*Tmax*	33	37	36	40	42	38	36	37	36	31.6
		Tmin	23	23	25	25	26	26	28	25	25	22.7
		D.T.R.	10	14	11	15	16	12	18	12	11	8.9
Elefsina	16718	*Tmax*	36	41	41	42	43	41	42	41	45	32.7
		Tmin	25	26	26	28	30	25	29	27	29	22.1
		D.T.R.	11	15	15	14	13	16	13	14	16	10.6
Aliartos	16674	*Tmax*	38	39	40	40	40	39	40	42	44	32.0
		Tmin	20	21	21	25	22	23	22	23	25	17.6
		D.T.R.	18	18	19	15	18	16	28	19	19	14.4
Larissa	16648	*Tmax*	38	40	41	40	41	39	42	43	43	33.1
		Tmin	19	20	21	21	21	23	21	22	22	17.5
		D.T.R.	19	20	20	19	20	16	21	21	21	15.6
Kos	16740	*Tmax*	31	36	38	38	38	37	37	38	38	28.7
		Tmin	21	23	27	28	29	25	28	28	27	21.2
		D.T.R.	10	13	11	10	9	12	9	10	11	7.5
Naxos	16732	*Tmax*	30	30	31	32	32	31	31	33	33	26.7
		Tmin	22	23	26	28	28	26	26	26	25	21.6
		D.T.R.	8	7	5	4	4	5	5	7	8	5.1
Heraklion	16754	*Tmax*	30	32	32	31	32	32	33	32	36	28.7
		Tmin	20	22	23	24	23	25	27	25	24	21.4
		D.T.R.	10	10	9	7	9	7	6	7	12	7.3
Tybaki	16759	*Tmax*	38	39	40	39	41	41	40	40	44	31.5
		Tmin	19	23	23	25	26	26	25	25	21	20.3
		D.T.R.	19	16	17	14	15	15	15	15	23	11.2
Kalamata	16726	*Tmax*	33	34	34	34	43	37	39	41	41	31.1
		Tmin	18	21	20	20	22	22	20	19	22	18.1
		D.T.R.	15	13	14	14	21	15	19	22	19	13.0
Corfu	16641	*Tmax*	35	35	39	40	41	41	39	41	34	30.6
		Tmin	18	20	20	22	23	22	22	21	22	18.0
		D.T.R.	17	15	19	18	18	19	17	20	12	12.6
Zakynthos	16719	*Tmax*	34	36	39	40	42	41	41	42	36	30.3
		Tmin	18	18	22	23	24	23	23	22	20	21.0
		D.T.R.	16	18	17	17	18	18	18	29	16	9.3

Explanation of symbols: *Tmax* maximum temperature, *Tmin* minimum temperature, D. T. R. diurnal temperature range, $\bar{T}max$ July long-term-average maximum temperature, $\bar{T}min$ July long-term-average minimum temperature.

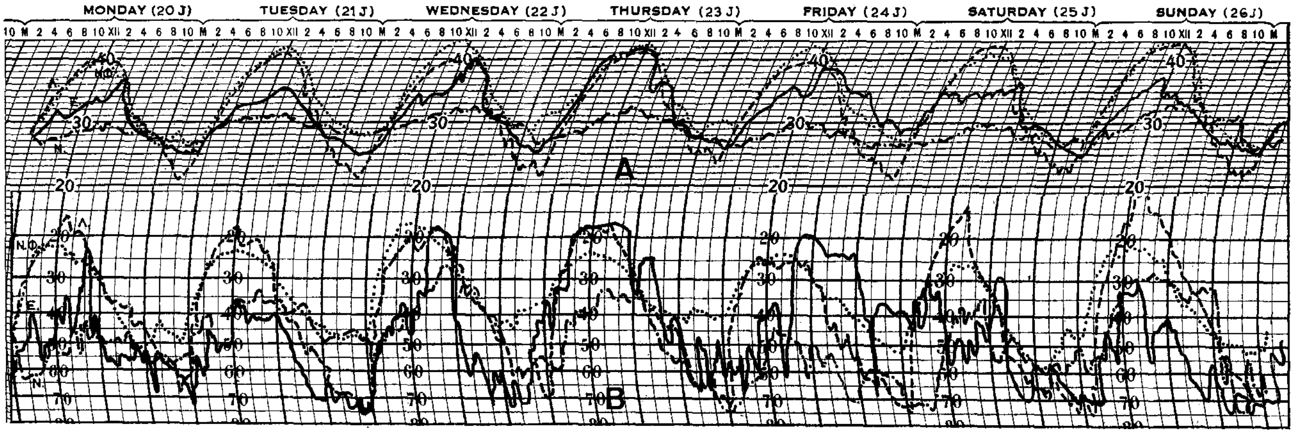

Fig. 8. Some typical registrations of (A) temperature and (B) relative humidity from Monday 20 July to Sunday 26 July 1987. Continuous line: Helliniko meteorological station, dashed line: Larissa, dotted line: New Philadelphia and dashed-dotted line: Naxos

which did not occur at the Elefsina meteorological station, although the latter is also a coastal station at a distance of a few kilometers from Helliniko. As a result of this last fact, the maximum temperature reached the value of 45 °C at the Elefsina meteorological station on 27th of July 1987. This maximum temperature values was the greatest during the heatwave's period not only for the Elefsina station, but for the whole of Greece as well. The fact that sea breezes do not occur simultaneously at all at Athens region's coastal meteorological stations, is a problem which is attributed to the interaction between mesoscale and synoptic scale circulation and has not yet been fully investigated (Prezerakos, 1985). Moreover, the sea breeze, wherever it occurred, was very weak and restricted to the coasts.

We can also realize from Table 1, that the minimum temperature values were high during most of the heatwave time period. This fact reduced the daily temperature range elongating thus the duration of the discomfort conditions, which were making people suffer ceaselessly even during the night.

There was also a remarkable contribution to the heatwave because of the fact that many hours during each day the temperature reading was close to its daily maximum value. This was derived by examining the thermographs of many meteorological stations distributed over Greece. Some typical of them are shown in Fig. 8 (a).

Table 2 shows the daily maximum, and the daily minimum values of Thom's discomfort index I_d (Thom, 1959). These values were very high during the entire heatwave, thus maintaining very discomfortable weather conditions for many hours each day, resulting in cancelling of all the civil services. It is well known (Thom, 1959) that, when $24 \leqslant I_d < 26$ 50% of the total population feels discomfort, when $I_d \geqslant 26$, the entire population feels discomfort, and when $I_d \geqslant 26.7$, the discomfort is very strong and dangerous. It is noteworthy to mention that Thom's index should be much higher if the warm air masses which had settled over Greece were not of a Saharan origin, that is Tropical continental (Tc). In some coastal cities where the humidity was also high, the weather conditions were really intolerable.

The last question which remains to be answered is, whether the heatwave phenomenon under consideration was really an unprecedented one. In order to give an accurate answer, this topic should constitute the subject of a specific investigation, including the analysis of data of many Greek meteorological stations, establishing adequate criteria this way. However, a heiristic answer could be given by saying, that maximum temperature values greater than those of the 19 to 27 July 1987 period have been recorded in the past, e.g. on 10th of July 1977, when the maximum temperature adopted the value of 48 °C at Elefsina and Tatoi meteorological stations as we have already mentioned in the introduction. Also maximum temperature values greater than 38 °C were recorded at most of the Greek meterological stations. Such maxima have been reported many times in the past

Table 2. *Daily Maximum and Minimum Values of Thom's Discomfort Index and Their Times of Occurrence from 19 to 27 July 1987 at Some Greek Meteorological Stations*

Meteorological Stations	WMO No.		Days of July 1987								
			19	20	21	22	23	24	25	26	27
Helliniko	16716	*Id max*	26.6	28.8	29.1	29.7	30.8	30.1	29.7	29.6	29.4
		Oc time LCT	1500	1800	1800	1800	1500	1500	1800	1500	1500
		Id min	22.1	22.4	22.9	23.7	25.3	24.9	26.2	24.2	24.2
		Oc time LCT	0600	0300	0300	0600	0300	0300	0300	0600	0600
N. Philadelphia	16701	*Id max*	29.8	30.7	31.3	32.2	31.4	31.4	31.2	31.5	31.8
		Oc time LCT	1500	1500	1500	1500	1500	1500	1500	1500	1500
		Id min	24.2	24.9	25.9	26.5	27.7	26.3	25.8	26.2	26.1
		Oc time LCT	0900	0900	0900	0900	0900	0900	0900	0900	0900
Thessaloniki (Mikra)	16622	*Id max*	27.5	27.4	27.7	28.8	29.8	28.4	28.8	29.1	28.7
		Oc time LCT	1800	1500	1500	1500	1500	1500	1500	1500	1500
		Id min	20.9	21.3	22.0	22.6	22.1	23.2	22.4	23.2	21.5
		Oc time LCT	0900	0300	0300	0300	0300	0300	0300	0300	0600
Larissa	16648	*Id max*	29.2	26.1	29.6	29.7	29.6	29.5	28.7	29.7	30.5
		Oc time LCT	1500	1500	1500	1500	1500	1500	1500	1500	1500
		Id min	19.8	21.5	23.18	22.8	22.1	22.5	22.0	22.5	19.2
		Oc time LCT	0600	0300	0300	0300	0300	0300	0300	0300	0600
Kalamata	16726	*Id max*	26.7	27.2	27.6	28.4	30.4	29.2	28.0	28.8	30.4
		Oc time LCT	1800	1500	1500	1500	1500	1500	1500	1500	1500
		Id min	19.0	21.6	21.6	22.1	22.3	22.1	21.6	22.0	20.9
		Oc time LCT	0300	0300	0300	0300	0300	0300	0300	0300	0600

Explanation of symbols: *Id* discomfort index; $Id = 0.4(T + T_w) + 4.8$; *T* dry bulb temperature and *Tw* wet bulb temperature; *Oc* time occurrence time; LCT Local Civil Time.

during similar yearly periods. The Metaxas/Kallos' (1980) investigation on heatwave in Greece was based upon that material.

Finally, running through the archives of the Hellenic National Meteorological Service, which are stored in magnetic tapes starting in 1953 with the exception of the Athens Observatory stored data, which have 1896 as a starting year, we can conclude that cases of 9 successive days with maximum temperature values more than or equal to 37.5 °C, have not been recorded at any Greek meteorological station with the exception of Larissa, where this occurred once. Moreover, the case of 8 successive days during which the maximum recorded temperature was greater or equal to 41 °C reported at most of the purely continental meteorological stations of eastern Greece from 20 to 27 July 1987 is really an unprecedented phenomenon concerning observations since 1953 and since 1896 for the Athens region, individually. Unfortunately, there is no sufficient data to accurately answer, whether the duration of very discomfortable weather conditions is an unprecedented phenomenon. There exists strong evidence, however, verifying that the loss of 1,500 lives is indeed an unprecedented phenomenon locally, as nothing similar has ever been reported before.

6. Concluding Remarks

From the study of the atmospheric circulation in the time period from 19 to 27 July 1987 based upon the mean 500 hPa height and its anomaly fields, we were able to conclude that the heatwave phenomenon having appeared over south Italy and the Balkans belongs to the synoptic scale and larger atmospheric circulation.

The main centre of action was a meridional blocking high meandering over the northeast Atlantic controlling the circulation and creating a deep low, situated at the eastern flank of the ridge, persisting over northwest Europe for many days, thus becoming the key system. This key system caused the intensive warm advection, towards south Italy and the Balkans, and the atmospheric circulation, to be extremely anticyclonic resulting in the negative advection of relative vorticity and the large scale subsidence in an area from Libya to the Balkans. Also an intense diabatic warming due to persisting sunshine on a very mountainous region as the Balkans and the subtropical jet stream located on a position being to the north of the Balkans created the heatwave time period which portrayed high temperatures having surpassed the value of 38 °C at most of the Greek meteorological stations for many days.

The fact that on 9 successive days the maximum temperature appeared to be greater or equal to 38 °C during the heatwave, was not unprecedented for all of the Greek meteorological stations, but 8 successive days with maximum temperatures greater or equal to 41 °C have never occurred since 1953 at Nea Philadelphia and since 1896 at the Athens Observatory meteorological stations.

The fact that the temperatures kept overall near the values of the maximum temperatures for many hours during the day, was unique for the majority of the Greek meteorological stations.

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