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SYNOPTIC PROCESSES FOR THE FORMATION OF CYPRUS LOWS

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SYNOPTIC PROCESSES FOR THE FORMATION OF CYPRUS LOWS

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SUMMARY - The Cyprus lows, an important weather type in the Eastern Mediterranean during the winter, is studied, mainly from a synoptic point of view.

We define *D day*, as the first day with a low in the Cyprus area, with at least two closed isobars, and with isobars analysed every 5 mbar.

We used the superposed epoch analysis for temperature in Limnos island, Greece and Nicosia, Cyprus, for rainfall in Nicosia and for wind in Limnos. This analysis showed that an abrupt fall of temperature and strong NE winds prevailed in Limnos, on day *D-2*. Also, rainfall in Nicosia started on day *D-2*. It then decreased for days *D* and *D+1*, probably due to SW winds during these days, and again increased up to about day *D+1*.

The synoptic characteristics common for the three winter months, showed the following:

a) Cyclogenesis in Cyprus came as a result of positive vorticity advection, mainly in the upper levels, associated with cold air invasion into the Mediterranean.

b) This vorticity maximum has been steered by a blocking anticyclone. On day *D-3* this maximum existed over Central Europe.

c) In most cases, this blocking anticyclone appeared after the genesis of a low over Western Europe. Anticyclogenesis took place between days *D-2* and *D-1*. It then extended northward and remained as a N-S oriented zone, significant and almost stationary, up to at least day *D+2*.

d) The most striking feature of this evolution in January and February appears to be the above mentioned rapid anticyclogenesis. Another significant Atlantic low, W of the former, must have contributed to this formation.

Processus synoptiques dans la formation de dépressions sur Chypre

RÉSUMÉ - Les dépressions sur l'île de Chypre, si importantes pour le climat d'hiver sur la Méditerranée orientale, sont examinées au point de vue synoptique. On définit *D day* le premier jour avec une dépression dans la zone de Chypre. Les caractéristiques synoptiques communes à trois mois d'hiver sont les suivantes:

a) la cyclogénèse sur Chypre se vérifie à la suite d'advection de tourbillon positif, spécialement aux niveaux supérieurs, associée à une invasion d'air froid sur le Méditerranée;

b) le maximum de tourbillon est dû à un anticyclone de blocage;

c) dans la plus grande partie des cas, cet anticyclone de blocage apparaît après la formation d'une dépression sur l'Europe occidentale;

d) l'aspect le plus surprenant de cette évolution semble être, aux mois de janvier et février, la naissance d'un processus rapide d'anticyclogénèse.

Processi sinottici nella formazione di depressioni su Cipro

RIASSUNTO - Le depressioni sull'isola di Cipro, così importanti per il clima invernale sul Mediterraneo orientale, vengono esaminate da un punto di vista sinottico.

Si definisce *D day* il primo giorno con una depressione nell'area di Cipro. Le caratteristiche sinottiche comuni a tre mesi invernali sono le seguenti:

a) la ciclogenesi su Cipro si verifica come risultato di avvezione di vorticità positiva, specialmente ai livelli superiori, associata ad invasione di aria fredda nel Mediterraneo;

b) il massimo di vorticità è dovuto ad un anticiclone di blocco;

c) il più delle volte, questo anticiclone di blocco compare dopo la formazione di una depressione sull'Europa occidentale;

d) il più sorprendente aspetto di questa evoluzione appare essere, nei mesi di gennaio e febbraio, l'insorgere di un rapido processo di anticiclogenesi.

1. INTRODUCTION

The Mediterranean, an area of maximum cyclogenesis frequency and cyclone tracks during the cold period of the year, is located south of the prevailing westerlies. Cyclogenesis normally takes place there with a low-index type of circulation (1). This implies that a blocking warm anticyclone prevails somewhere north or northwest of the Mediterranean. In this respect, it is known [see e. g. (2), (3), (4)] that blocking anticyclones in this area form and persist with high frequency. But cyclogenesis in the Mediterranean takes place also in preferred positions. The Gulf of Genova is well known as a place with maximum cyclogenesis frequency. To this cyclogenesis, the corresponding blocking anticyclone contributes by steering cold air-masses and upper vorticity maxima, around its eastern flank over the relatively warm waters, but the orography along the Northern coast also plays an important role (5).

It is evident from the above that, from a climatological point of view, a main cyclogenetic factor is the flow of cold air masses over the relatively warm winter waters. Large amounts of sensible and latent heat flux and therefore increased instability of the potential type [(6), (7)] are the main factors, which form or rejuvenate, and to a certain degree cause the movement of, the surface lows. Diagnostic studies [see e.g. (7, 8, 9)] showed that these factors are powerful during this period of the year in the whole Mediterranean

basin, but mostly in its central and the eastern parts.

The term cyclogenesis in this paper should not be restricted to the formation of an altogether new surface depression, but also to a rejuvenation of an already existing vortex, always over the sea during the winter. As for the Eastern Mediterranean (6), in most cases cyclogenesis there takes place initially elsewhere and then the low moves to E-SE, over the Cyprus area, where it may become stronger and persist for a longer time.

EL FANDY (10) gave a good description of the Cyprus-low effect on the weather of the East Mediterranean and of the Middle East countries. He attributed its formation to the flow of arctic air masses into the East Mediterranean from areas north of it. This opinion has been supported by almost everyone who studied the phenomenon (6, 11, 5, 12).

In this work, we intend to study mainly the general synoptic conditions leading to the formation and development of Cyprus lows. We will also try to understand the dynamic and thermodynamic factors which contribute to this development.

2. DATA AND METHOD USED

The method used in this work is based upon a selection of cases or dates of development for the first time, of a well developed low over the East Mediterranean. This does not mean necessarily that this low has formed *in situ*, because it may have come there from elsewhere. But this low should not be

a thermal one, as is the case in many favorable places in the Mediterranean, but one with a three dimensional structure. We found that this is the case when the surface low has at least two closed isobars drawn every 5 mbar. Furthermore, we imposed the condition that this low should persist there for a period of at least two days.

During the period 1958-1972, 11 such cases were found in December, 13 in January and 9 in February.

D day is defined as the first day with such a low in the Cyprus area. The synoptic maps used to define *D days* were the daily *Täglicher Wetterbericht*, of the German Meteorological Service.

Mean maps were then calculated, for 500 mbar, 1000/500 thickness and surface pressure, for days *D-3*, *D-2*, *D-1*, *D*, *D+1* and *D+2* in December, January and February. The data used for this calculation were daily grid-point data of the English Meteorological Office data bank. They are given for every 5 deg. lat. and 10 deg. long., and cover the N Hemisphere north of 20 deg. lat. Only a part of this data, between 70 deg. W and 80 deg. E, has found useful for this work.

Along with the mean grid point values, their *standard deviation* has also been calculated. Using the long-term means of the 1949-1972 period, as «normal» values, the mean anomaly values are calculated, along with their corresponding *t-values*, to test their significance. Isopleths are then drawn for pressure and 500 mbar height, as well as the isoanomalies for these parameters and the thickness maps. When an anomaly maximum or minimum area is significant at least at the 95% level, the isoanomaly which encloses this area is drawn with a continuous line, otherwise with a dashed one.

A strong pressure anomaly maximum, positive or negative, can be considered as a mean negative or positive vorticity maximum, respectively, because the time-mean values used for the estimation of the anomaly can be considered approximately equal to space-mean ones used for the estimation of the mean geostrophic relative vorticity. This is mainly

true where no permanent seasonal surface pressure patterns exist (1).

Along with the mean maps and anomalies, many useful results will be derived indirectly from a superposed epoch analysis for some weather elements, before and after the formation of the Cyprus low.

3. THE SUPERPOSED EPOCH ANALYSIS

In synoptic climatology several results may be indirectly obtained by studying the mean time variation of some weather parameters during the life cycle of a phenomenon, in our case the first formation of the Cyprus low. The following weather elements were examined for the stations of Nicosia, Cyprus, and Limnos island in the middle of the north Aegean:

- a) the maximum temperatures at both stations by month (fig. 1 (a));
- b) the minimum temperatures at both stations by month (fig. 1 (b));
- c) the diurnal temperature range at both stations by month (fig. 1 (c));
- d) the 24 hour precipitation amounts for Nicosia for the whole winter (fig. 2);
- e) the surface winds in Limnos, for the whole winter, along with its constancy (fig. 3).

3.1 The temperature epoch analysis

In Limnos the maximum temperature shows an abrupt and very significant fall from about two or three days before *D day* up to *D day*. In Nicosia this fall starts about a day later and it is not significant in every month.

In Limnos the minimum temperature shows the same type of fall as the maximum temperature but it is not as large and significant as with the maximum. In Nicosia a slight fall after *D day* appears but it is not significant in most cases.

The diurnal range shows a fall up to about the *D day*, but insignificant, in some cases, in Nicosia.

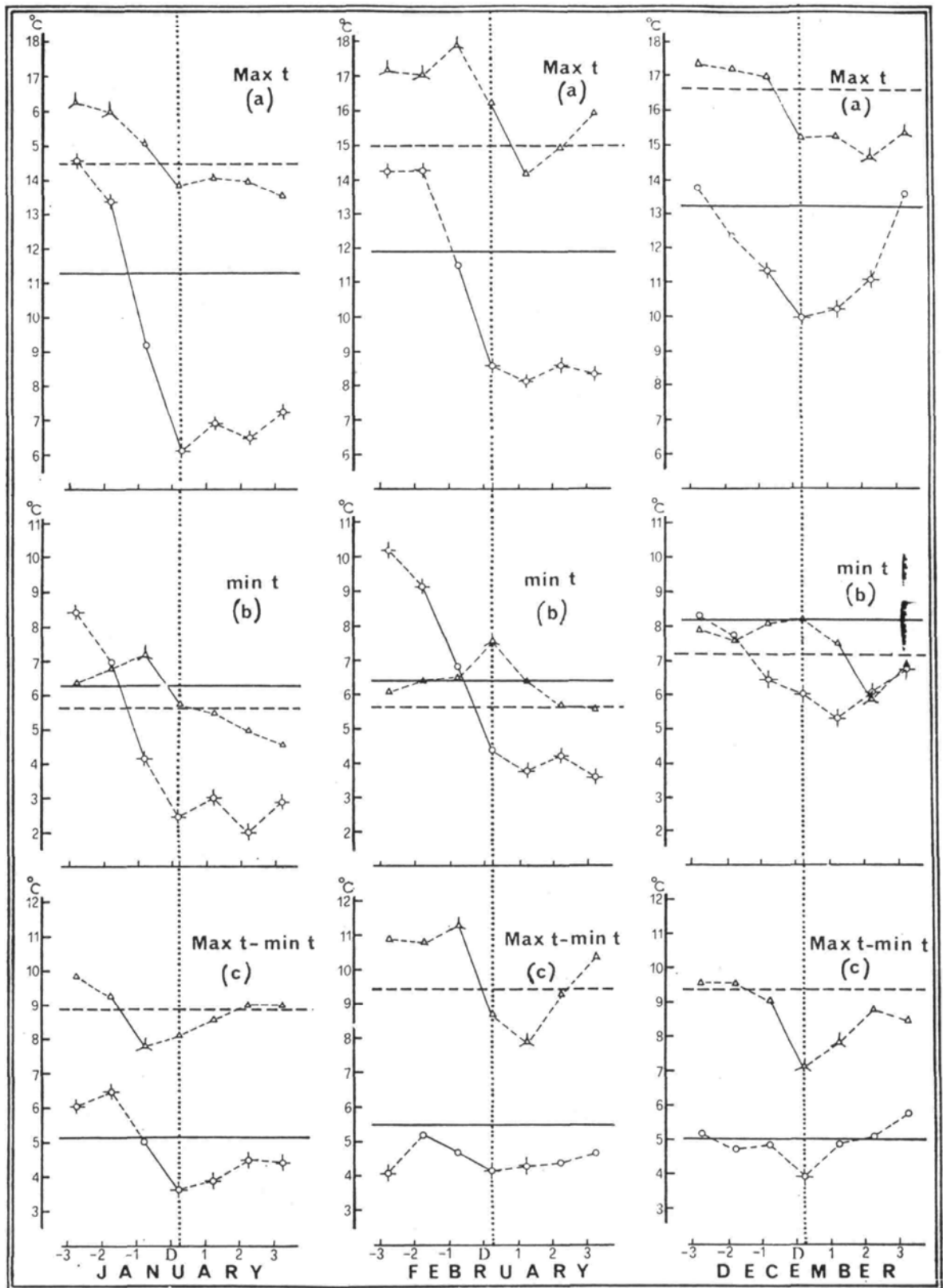


Fig. 1 - Superposed epoch analysis in Limnos island (○) and in Nicosia Cyprus (△), for: (a) max. temperature (°C), (b) min. temperature (°C) diurnal temperature range (°C). Horizontal lines show the normal corresponding values, 1951-1972 in Limnos (continuous) and in Nicosia (dashed). Open circles over cross ⊕ and extended triangle △ for values with statistically significant departure from normal. Consecutive values with statistically significant difference are joined by a continuous line (95% level at least), otherwise dashed

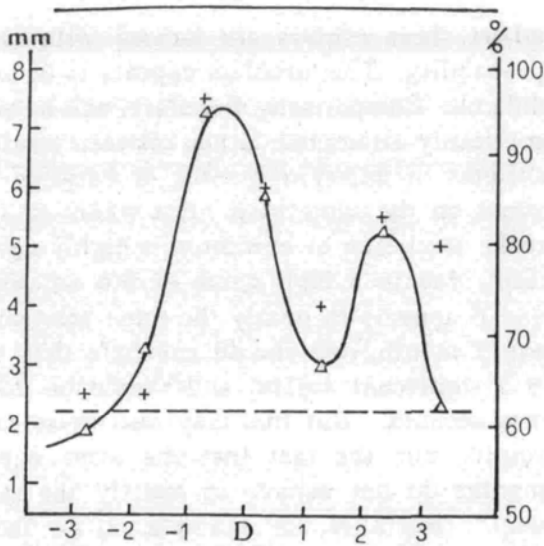


Fig. 2 - Triangles: mean 24h precipitation amounts in Nicosia. Crosses: number of rain-days (%). Dashed horizontal line: normal mean 24h rainfall during the winter months

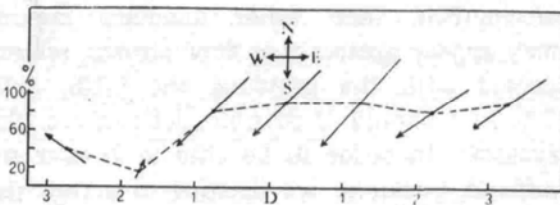


Fig. 3 - Resultant wind for the 31 winter cases at Limnos island. Dashed line indicates the constancy (%) of the wind (— corresponds to 5 m sec⁻¹)

The most striking picture in the above temperature epoch analysis is the marked temperature fall in the Aegean, mainly during January and February. This cold invasion substituted rather warm air masses, or at least masses with temperature above normal. This is also the case for Nicosia but, there, all differences are slighter.

The rather high air-temperature at D-3 and D-2 should give an indication of rather warm sea temperatures. The latter are a strong cyclogenetic factor in the Mediterranean when cold invasion takes place, increasing the sea-air temperature difference. It establishes also unstable conditions and increases the water vapor content of the lower and, through instability, the upper layers of the air mass, when a sufficiently long run over the sea takes place.

3.2 The rainfall in Nicosia

It is known that the 24-hour rainfall amount is not a normal variable. Comparisons, therefore, for significance are not as easy as in case of temperature. We had to combine the three months and examine the total 31 cases. When a characteristic in this sample has present in everyone of the months (not shown here), it was considered significant and will be discussed in the following.

The mean 24-h rainfall amounts and frequencies (fig. 2) show an abrupt increase from day D-3. But this increase stopped on day D-1 or D day. A significant decrease takes place afterwards for one or two days and a second increase follows, up to a secondary maximum on about day D+2.

This rainfall epoch distribution could be attributed mostly to the fact that upward vertical velocities and large rainfall amounts accompany the cyclogenesis process. The rainfall decrease on the other hand, should be attributed to the effect of the Troodos mountains, in relation to the wind direction.

In fact, when SW winds are established in Cyprus, these are katabatic in Nicosia. Common experience in the whole Mediterranean shows that mountain effects are very strong factor affecting precipitation, because the air masses are in general convectively unstable, due to low level humidity increase. These cold or warm air masses are, before entering the Mediterranean, in general fairly dry.

3.3 The wind over the Aegean

The cold invasion, shown in the temperature analysis of Limnos, is roughly in accordance with the wind change there. A NE wind with a high constancy prevailed on day D-1 and continues up to the last considered day, D+3. But from D+2 on the wind became more easterly and decreased in force.

There is a noteworthy difference between the time of the temperature fall and the establishment of NE winds. The former started earlier and finished earlier. If we accept that this difference in time is statistically significant, one might attribute the earlier

temperature fall to the effect of thick cloudiness and precipitation and moderately cold invasion, due to the passage of a front or a low, moving from west to east, along the Mediterranean. In fact, experience (1) shows that strong cold invasions in the Aegean come as a result of two cold front passages. The first, associated with a depression, is moving from W to E and covers the area with a polar air mass, strongly modified by the sea during its passage through the Mediterranean. The second front, moving from north to south, is associated with an upper vorticity maximum. This covers the area with much colder air. This second flow causes surface cyclogenesis, as the upper trough approaches the warm Mediterranean sea.

The above ideas are not clearly shown in our data and, in fact, it is not certain that the time difference between the onset of the wind and the one of the temperature fall is statistically significant.

Unfortunately, there were no data available to see if this second flow enters the Mediterranean after passing over the Anatolia plateau.

Comparing the temperature and the wind behaviour after D day, we observe another difference. While the wind continues to be northerly, the temperature stopped falling. But in fact, the wind after day D+1 becomes more easterly and it is weaker. This could be caused by the fact that the Cyprus low is now deep enough to affect a large area and to modify the wind in the Aegean. This wind change might have stopped the cold air advection and thus the temperature fall stopped. The weakening of the wind, on the other hand, may have permitted the sensible heat flux to be an important factor, warming to certain degree the air mass.

4. THE SYNOPTIC STUDY AND EVOLUTION

The mean anomaly charts are based upon a relatively small data sample. One therefore expects the position and strength of the mean maxima and minima of the anomalies to depend upon the sample. Also, a proper statistical treatment should include an area

where these centers are located with large probability. This problem appears to be very difficult. Comparisons, therefore, will be very cautiously attempted, either between weather systems in different months or between systems on the same map. But when an anomaly maximum or minimum is highly significant, due to a high value of the t-statistic, and it appears in nearly the same position in every month, one should conclude that this is a significant system and should be taken into account. But this may also cause false results, due to the fact that the three winter months do not behave in exactly the same way. December, for example, is, for the E Mediterranean, a month which belongs to autumn rather than to winter.

There is also another point worth mentioning. When a strong anomaly center persists in a certain area, created by some physical mechanism, then other anomaly maxima may appear upstream or downstream, teleconnected with the previous one [(13), (14)]. One then should, if possible, define the anchor system. In order to be able to answer this difficult question, we decided to accept that the anchor system is the one with the strongest anomaly, either maximum or minimum.

4.1 The 500 mbar charts

From the overall configuration of the anomaly field one can see that a blocking warm anticyclone over W or NW Europe appears to be one of the anchor systems. Also, an upper low on its E flank is steered by the above anticyclone and caused cyclogenesis. But there are some differences in position and behaviour of the above two systems for the three winter maps.

a) In December, this anticyclone existed already on day D-3 and persisted for the following six-day period over Spain and the W Mediterranean, moving slowly to N until D day, and then again slightly to south. It is increasing in strength up to a maximum days D and D+1.

b) In January, this anticyclone appeared suddenly on day D-1. It may have come from the E coast of the U.S., but it was not

significant there. Abrupt anticyclogenesis took place between days D-2 and D-1, which formed an oblong, N-S, oriented positive anomaly zone, between the W Mediterranean and high latitudes. Then, during the following days it persisted strongly and very significantly, with a slow but steady movement to the north.

c) In February a similar warm anticyclone appeared on day D-2, but it was significant and strong only on day D-1. It also, as in January, showed slight movement to the north.

An anomaly minimum on the E or the NE flank of this anticyclone seems to be at least equally significant:

a) In December, a negative anomaly belt from the Balkans up to almost Greenland, with a separate maximum over the Balkans, appeared on day D-3 but it was not significant, contrary to the anticyclone which on D-3 was already highly significant during this month. It moved then, to SE, becoming stronger, and on day D+2 is found over the E Mediterranean coast.

b) In January, contrary to December, this low was already significant and strong over NW Europe on day D-3. It then moved to E, and as the anticyclone developed the low changed its track, and between days D-2 and D-1 it moved to SE. On D day it is just W of Cyprus.

c) In February, the low behaved the same way as in January. It existed before the anticyclogenesis took place and followed the same track with a similar speed.

The above two systems seem to be the anchor systems. The low should be considered as more important, because, in January and February, it already existed well developed on day D-3, contrary to the anticyclone which developed one or two days later. But by day D+2, the anticyclone was well developed. We might conclude that the low caused or contributed to the anticyclogenesis, but the high then steered the low to SE and this caused the low level cyclogenesis, as the

positive vorticity advection area is found over the warm sea.

There are some other systems which existed significantly on the 500 mbar anomaly charts:

a) a low on the W-flank of the anticyclone preexisted in January and February. This may have contributed to the anticyclogenesis;

b) a warm anticyclone covered the E Mediterranean on day D-3. This high moved then rather fast to E-NE, over Siberia. This high might have caused a warming of the sea over the central and the east Mediterranean before the positive vorticity advection entered there, to cause a three dimensional structure favorable for the low.

4.2 Surface charts

These charts showed an evolution corresponding to 500 mbar changes:

a) December. On days D-3 and D-2 no significant surface lows appeared in the Mediterranean or even in Europe. The surface low appears only on day D-1, over the E Mediterranean. It acquired its maximum strength on days D and D+1, and then, filling up, it continued its movement to NE, out of the Mediterranean.

b) January. Contrary to December, in January a significant surface low appeared over the northern Adriatic Sea, though the anomaly maximum is found slightly to NE. It moved then to SSE and covered Cyprus on D day. Then, it continued to move to E and then to NE, though a separate thermal surface low remained in the E Mediterranean.

c) February. A weak and not significant low existed over Sicily on D-3. It moved to the central Mediterranean on day D-2, still remaining insignificant. It becomes significant only on day D-1, moving further to E. On D-day the low appears over Cyprus. Then, the negative anomaly moved to E-NE, leaving a weaker thermal surface low in the E Mediterranean.

4.3 The air masses

The air masses, shown in thickness anomalies, behaved in accordance with the above described pressure systems.

a) In December, a significantly warm air mass covers NW Africa. Insignificant positive temperature anomalies cover almost the whole Mediterranean, and especially the E, on day D-3.

This warm air-mass had advected to N by the W flank of the anticyclone, located on that day over the W Mediterranean, and on days D and D+1 reached very high latitudes. At the same time, cold air masses were advected southward by the E flanks of this anticyclone. They entered for the first time the N part of the central Mediterranean on the day D-2, and on D-1 they covered the whole central Mediterranean. On D day they continued to move to SE, but from then on no significant change appeared. It seems that a cold front passed Cyprus on day D+1 or perhaps a little earlier.

Some cold air moved to N, by in this position it is not abnormal and is not shown in the anomalies.

b) In January, almost the whole Mediterranean is covered by significantly warm air masses on day D-3. Cold air on that day was located over Great Britain. This coupled warm and cold air moved as follows:

The warm air moved to E and then to NE and on day D+2 remained significant over Iran. The cold air moved to E on D-2 and then to SE. The cold air covered Cyprus between day D-1 and D, and up to day D+2 it did not show any appreciable change, as the case for December. The warm air mass which was associated with the blocking anticyclone, persisted along a N-S oriented zone, with its maximum at about 10° E and 70° N, and reaching into the SW Mediterranean. On day D+2 it remained associated with the highly significant blocking anticyclone.

In January cold air must have advected on days D+1 or D+2 from the E Mediterranean to E-NE, but since it is found in areas with normally cold air, it is not apparent in the anomalies.

c) In February, too, the E Mediterranean and E Europe is covered by a significantly warm air mass, with its center over the Black Sea. On day D-2, cold air appeared in the W Mediterranean, not statistically significant. The warm air of the E is moving steadily to NE, leaving the Mediterranean. On D-1 the cold air covers the central Mediterranean, moving to E. The E Mediterranean has been completely covered on day D+1. After wards, as in the previous months, no appreciable change is observed.

The warm air mass of the blocking anticyclone remains in an oblong shape, from Spain up to NE Atlantic, during this month.

The above-described warm and cold air configurations and movements appeared quite uniformly during the three considered months in accordance with the movement of the pressure systems, to form a proper three-dimensional structure.

5. GENERAL RESULTS AND DISCUSSION

a) Cyclogenesis in the E Mediterranean has been produced as a result of advection of upper vorticity maxima, associated with cold air masses.

b) This movement has been caused by a warm blocking anticyclone located over W Europe and E Atlantic.

c) The blocking anticyclone, in January and February developed after, rather than before, the upper low on days D-2 and D-1. It developed in the south, but gradually it extended to high latitudes. It may have been generated by the contribution of the aforementioned low and of another low, located to the west of it. The mechanism of this key anticyclogenesis has not been explained.

d) Once formed, the blocking anticyclone became the anchor system and dominated the air circulation over a large area.

e) The other warm anticyclone which moved from the E Mediterranean to Iran and remained there might be a teleconnected system. Below this anticyclone, on the sur-

face, negative anomalies exists, with the Siberian anticyclone being further to the NE, remaining without a significant change.

As a general result, we believe that main factor for the cyclogenesis in Cyprus in the

formation, extension to the north, and reinforcement of the blocking anticyclone over W Europe - NE Atlantic. The physical mechanism for this formation remains to be discovered.

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APPENDIX

The maps of the following pages show the 1000/500 mbar thickness, 500 mbar levels and surface pressures. Covering the months of December, January and February and the days D-3, D-2, D-1, D day D+1, D+2. The thick lines (continuous or dashed) show the anomalies from the normal.

