

# CONTINENTAL POLAR OUTBREAKS INTO THE LEVANT AND EASTERN MEDITERRANEAN

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## ABSTRACT

Continental polar outbreaks into the Levant and eastern Mediterranean regions originate in vast continental regions over Asia and Europe, causing respective unique weather conditions—cold, dry, and stable. These north-easterly winds have important environmental implications for agriculture, cold stress, and air pollution, which were the motivation for this study. They are exemplified here by statistical and synoptic study of such events over Israel. Seventy-two days of such outbreaks were observed during 6 years (1983–1988), all of them between October–May associated with different synoptic patterns. The typical duration of these events was of two categories: short events of 1–2 days, and long events of 4–5 days. The latter are the result of ‘quasi-stationary’ systems whereas the short ones are due to the passage of disturbances over the eastern Mediterranean. The highest frequency is in December, with 28 days (between 1983 and 1988), compared with 13 days in January and 8 days in February. The decrease in frequency towards February can be attributed to changes in the cyclone’s trajectories, and to pressure gradient magnitude between the anticyclone over Asia and Turkey and the lower barometric pressure over the Mediterranean. These events have a typical course of pressure increase preceding the outbreak and during its first 2 days, and then a pressure decrease that is mostly accompanied with temperature increase.

KEY WORDS: continental polar outbreaks; Siberian anticyclone; polar ridge; Red Sea trough; vorticity; Levant; eastern Mediterranean; Israel.

## 1. INTRODUCTION

Continental polar air masses are frequent during the winter season in the Mediterranean basin, especially over the Adriatic and north Aegean seas. The air masses originate in an anticyclone over Russia, barometric ridges over the Balkan region and north and central Europe, producing cold and dry air flow. This cold, dry, and stable air blows mostly through mountain passes, creating the Mistral and Bora winds. The air masses break out into the warm and wet Mediterranean basin, creating or intensifying cyclones and producing rainstorms (Air Ministry, Meteorological Office, 1962; Alpert and Reisin, 1986).

This study refers to the eastern Mediterranean and Levant region, defined as the countries of the east shore of the Mediterranean from Egypt to, and including, Turkey (Vianna, 1979).

The air masses penetrate the region from the easterly sector passing through the continental path (Saaroni, 1993). Polar outbreaks into the Levant also occur with northern and north-western flow. However, these outbreaks are not connected to dry and stable air conditions and may cause rain or snow, a subject not discussed in this article. Here, the synoptic characteristics of continental polar outbreaks, their frequency, and their distribution, are analysed.

### 1.1. Data base

The study is based on 6 years from the 1983–1988 period, basically from the Israel Meteorological Service because Israel represents the centre of the region referred to. The synoptic patterns were classified according to a

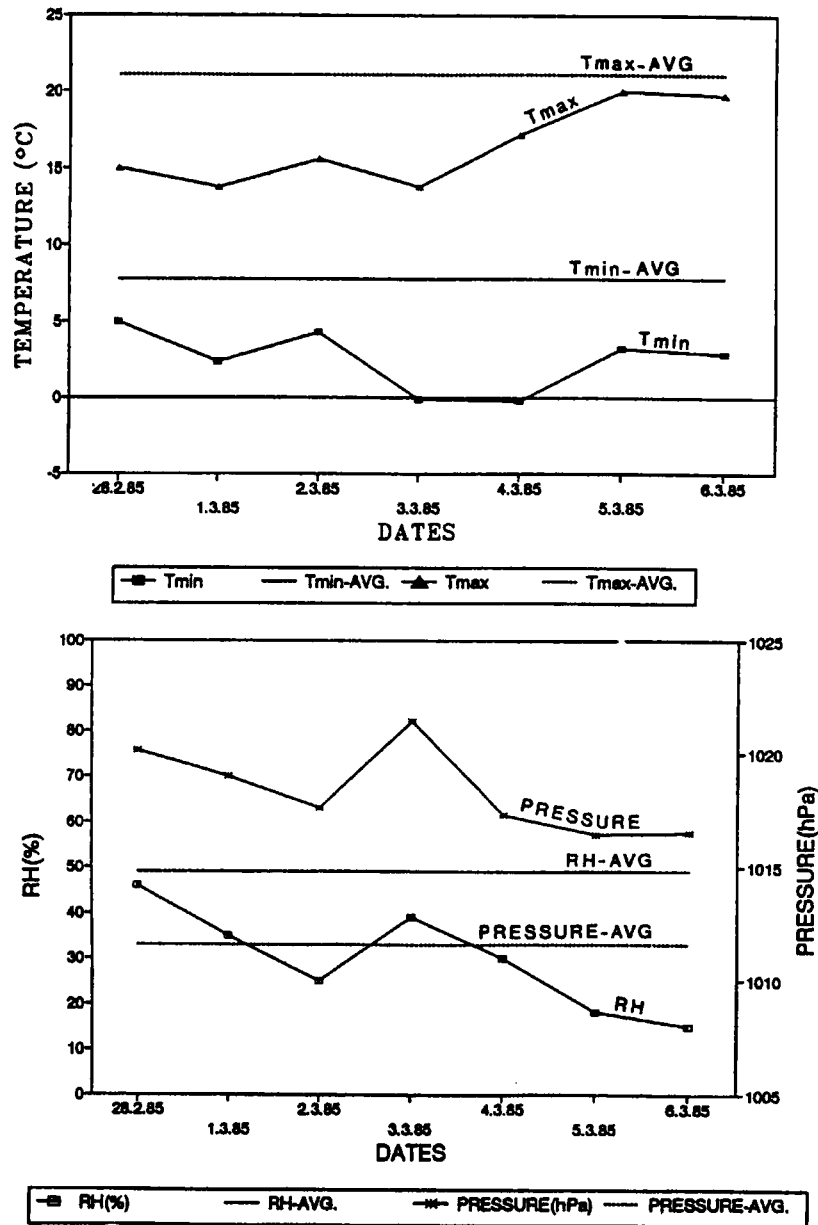


Figure 1. (a) Minimum and maximum temperatures for 28 February 1985 to 6 March 1985 compared with the decadal average at Bet-Dagan station. (b) Relative humidity and surface pressure, 1200 UTC

manual generic classification (Yarnal, 1993). The synoptic maps are produced by software, developed by Neeman and Alpert (1990), based on the European Centre of Medium-range Weather Forecasting (ECMWF) initialized analyses.

### 1.2. Continental polar outbreak episode

Continental polar outbreaks into the Levant and eastern Mediterranean basin may cause cold, dry and stable weather conditions. Figure 1 (a and b) expresses the minimum and maximum temperature, relative humidity and surface pressure (at 1200 UTC) in comparison with the decadal average for March at the Israel Meteorological Service station at Bet-Dagan (situated on Israel's coastal plain) during a typical event from 28 February 1985 to 6

March 1985. It illustrates that air mass characteristics during a continental polar outbreak along the Mediterranean coast and the typical pressure pattern, which is higher than the monthly average but the highest values appear only at the beginning of the event, as will be discussed later.

## 2. SYNOPTIC CHARACTERISTICS OF CONTINENTAL POLAR OUTBREAKS

### 2.1. Lower atmospheric levels

Continental polar outbreaks into the Levant and the eastern Mediterranean basin are part of the penetration of polar anticyclones. The centre of the anticyclone can be found over western Asia, the Caucasus—particularly the Armenian Plateau, central Turkey and the Balkans (Lydolph, 1977; Takahashi and Arakawa, 1981). This quasi-steady system, formed by the climatic and physiographic characteristics of Euro-Asia, produces a thermal anticyclone over Asia during the cold season. Barometric ridges from the anticyclone can penetrate the Levant and eastern Mediterranean regions when these regions are not influenced by a dominant synoptic disturbance, e.g. the Cyprus cyclone or the North African cyclone.

The synoptic systems characterizing the continental polar outbreaks are demonstrated by a few examples. The synoptic maps introduce isohypses at the 1000 hPa level and isotherms at the 850 hPa level (1200 UTC) in order to emphasize the cold advection. The maps show isohypses in decametres (dam) with a 2 dam interval, and isotherms have an interval of 3°C. It must be noted that these examples are not expressing different weather types or circulation of continental polar outbreaks, but different synoptic patterns accounting for similar weather conditions. The main difference is in the location of the anticyclone. The examples are:

- (i) The Caucasus—a branch of the Siberian anticyclone. The interior of the Transcaucasus, particularly the Armenian Plateau, which is well isolated from marine influences at either end, induces a local high pressure system due to thermal effects (Lydolph, 1977). An example is taken from 16 December 1986 (Figure 2 (a)).
- (ii) Central Asia—the synoptic map from the 3 March 1985 (Figure 3 (a)) shows direct advection from the Siberian anticyclone toward the eastern Mediterranean through the barometric ridge centred over north or central Asia.
- (iii) Turkey—a local anticyclone is frequently created over Turkey during the winter owing to the topographic structure, causing a continental climate over the Anatolian plateau, which is a closed interior basin, similar to the Armenian Plateau. Barometric ridges extending from the Anatolia plateau toward the Levant region may cause continental polar air mass advection. The synoptic map from 13 November 1988 (Figure 4 (a)) shows a situation where the anticyclone is centred over Turkey and is a part of the ridge centered over Asia. The synoptic map from 31 December 1988 (Figure 5) demonstrates a situation with an anticyclone over central and eastern Turkey and southern Caucasus, with no apparent connection to the Siberian anticyclone. It should be noted that this anticyclone is connected with a ridge covering western Europe, although the continental polar outbreaks into the Levant and the eastern Mediterranean originate from the anticyclone over Turkey.
- (iv) The Balkan region and central Europe—continental polar outbreaks from this region occur when the barometric ridge expands into the eastern Mediterranean basin. Tokatly-Levy analysed such a November event in 1958 (Tokatly-Levy, 1960). The synoptic map from the 3 December 1986 (Figure 6) also shows a continental polar outbreak from the Balkan region. A local anticyclone can develop over the Balkan peninsula during winter, similarly to that over the Anatolia Plateau in Turkey.

In fact, all synoptic situations described above are characterized by similar conditions without dependence on the detailed structure of the pressure system, such as the location of the pressure maxima.

In all the above-mentioned synoptic scenarios another system is also usually present over the southern Levant, i.e. the Red Sea trough. The trough location and configuration is not fixed, but it appears during most of the continental polar outbreaks into the region. The Levant region is located between the barometric ridge from the northern side, and the Red Sea trough from the southern side. The pressure gradient developed between the ridge and trough causes easterly winds, often quite strong, in the Levant region. The lee-low effect across the Jordan valley may contribute to a deepening of the Red Sea trough. It is clearly noticed in Figures 2 (a), 3 (a), 4 (a), 5, and 6, not only by the pressure trough but also by the warm tongue of air. The mean sea-level maps for January (Air

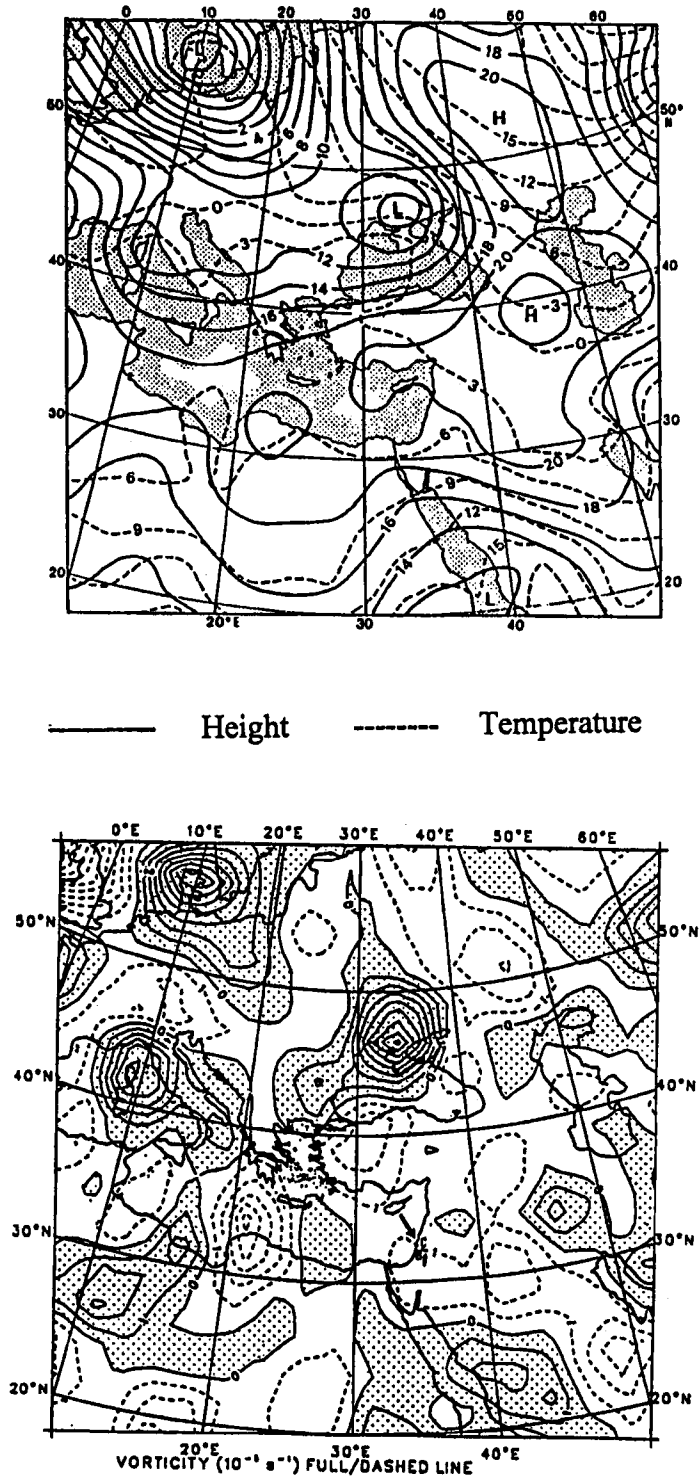


Figure 2. (a) 1000 hPa height and 850 hPa temperature for 16 December 1986, 1200 UTC, height and temperature intervals are 2 dam and 3°C, respectively. (b) 1000 hPa vorticity for 16 December 1986, 1200 UTC, vorticity intervals are  $10^{-5} \text{ s}^{-1}$ , positive values are dotted

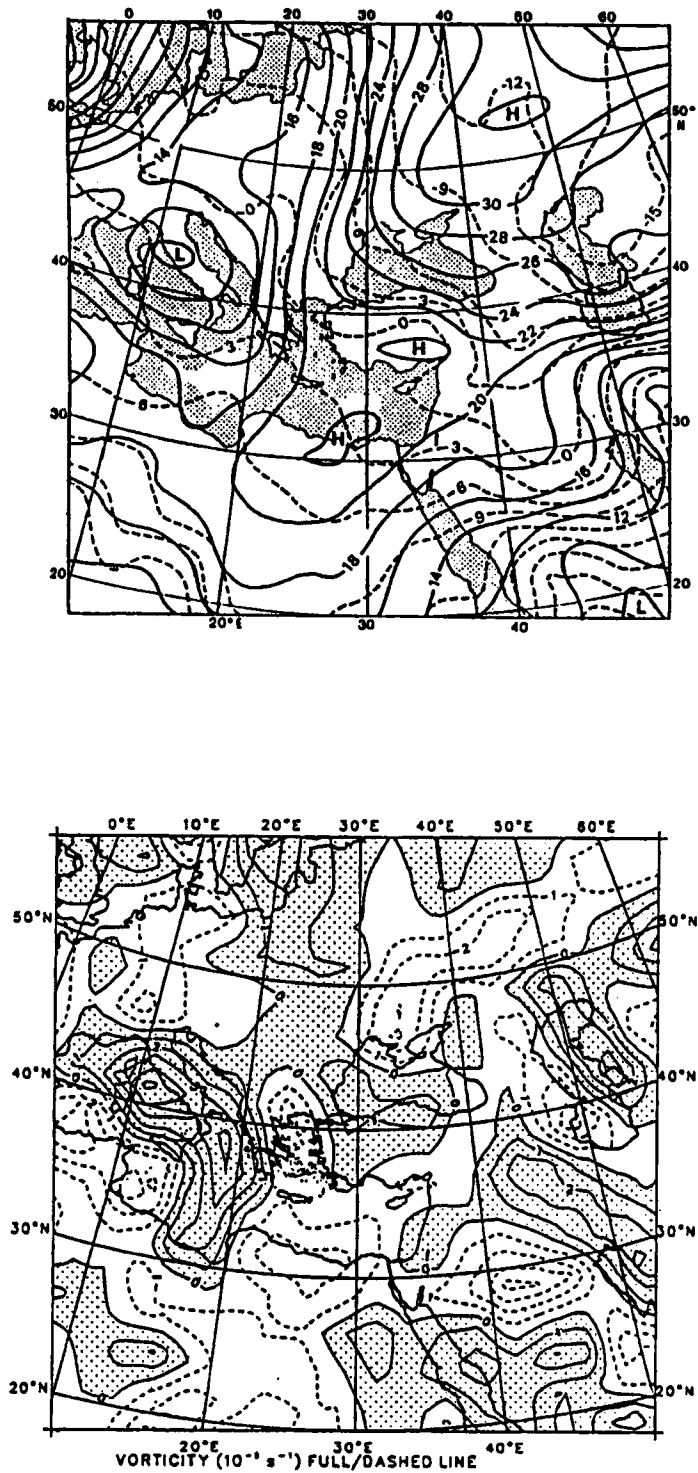


Figure 3. (a) As in Figure 2(a) but for 3 March 1985. (b) As in Figure 2(b) but for 3 March 1985.

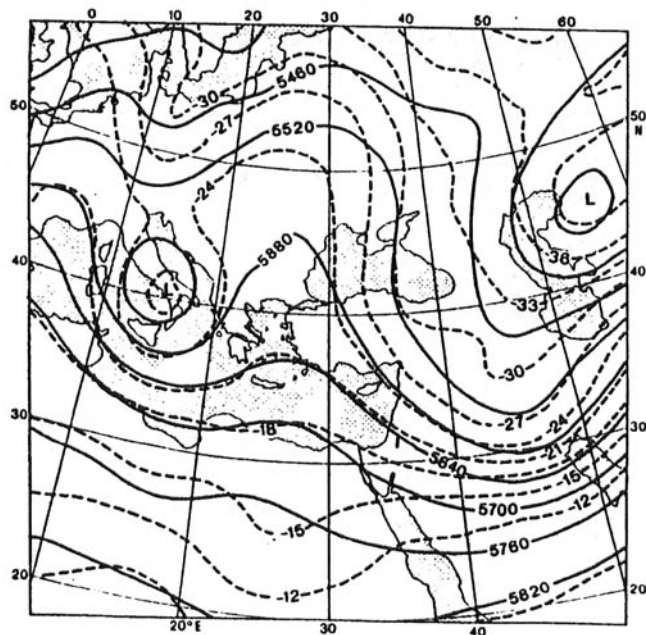


Figure 3. (c) 500 hPa height and temperature for 3 March 1985, 1200 UTC, height and temperature intervals are 6 dam and 3°C, respectively

Ministry Meteorological Office, 1962, p. 60) expresses the significance of the 'quasi-stationary' systems, such as the Red Sea trough and the polar ridge, over the region.

### 2.2. Medium and high troposphere levels

The Siberian anticyclone is a cold and shallower anticyclone that generally reaches up to a 800 hPa level (Barry, 1982). Although the lower atmospheric level is influenced by an anticyclone or by a barometric ridge, the middle and higher troposphere is influenced by a cyclone or a barometric trough (Lydolph, 1977). During most continental polar outbreaks, the Levant and eastern Mediterranean basin are situated on the rear side of the upper trough, with a north-westerly flow. The upper-level height and temperature values at the Levant region are below average. For example, the 500 hPa map from 3 March 1985 (Figure 3 (c)) represents the upper trough, which is oriented from north-east to south-west, while the Levant and eastern Mediterranean basin are situated beneath its inactive rear side. This circulation is typical for most continental polar outbreaks.

## 3. FLOW CHARACTERISTICS—CYCLONIC OR ANTICYCLONIC

A look at the 1000 hPa charts (e.g. Figures 2 (a), 5 and 6) gives the impression that the Levant and part of the eastern Mediterranean regions are influenced by a trough (the Red Sea trough) from the south rather than by a ridge from the north. A more objective approach is to examine the relative vorticity field for indicating which of these systems is dominant. Negative relative vorticity expresses anticyclonic flow and positive expresses cyclonic flow (Holton, 1992).

During October–May of 1983–1988, 72 days were found to possess the following characteristics typical for continental polar outbreak: (i) an easterly flow over Israel (direction within the sector of 030°–150° for at least 24 h; (ii) a below normal 850 hPa temperature at Bet-Dagan, Israel (point B on Figure 2 (b)). These cases do not include situations where any cyclonic disturbance influenced the eastern Mediterranean basin. Vorticity values at the 1000 hPa level were examined at the centre of the Levant region (32.5°N, 35°E, point C on Figure 2 (b)) on these days in order to study the flow characteristics near the ground, because continental polar outbreaks are known to be shallow systems.

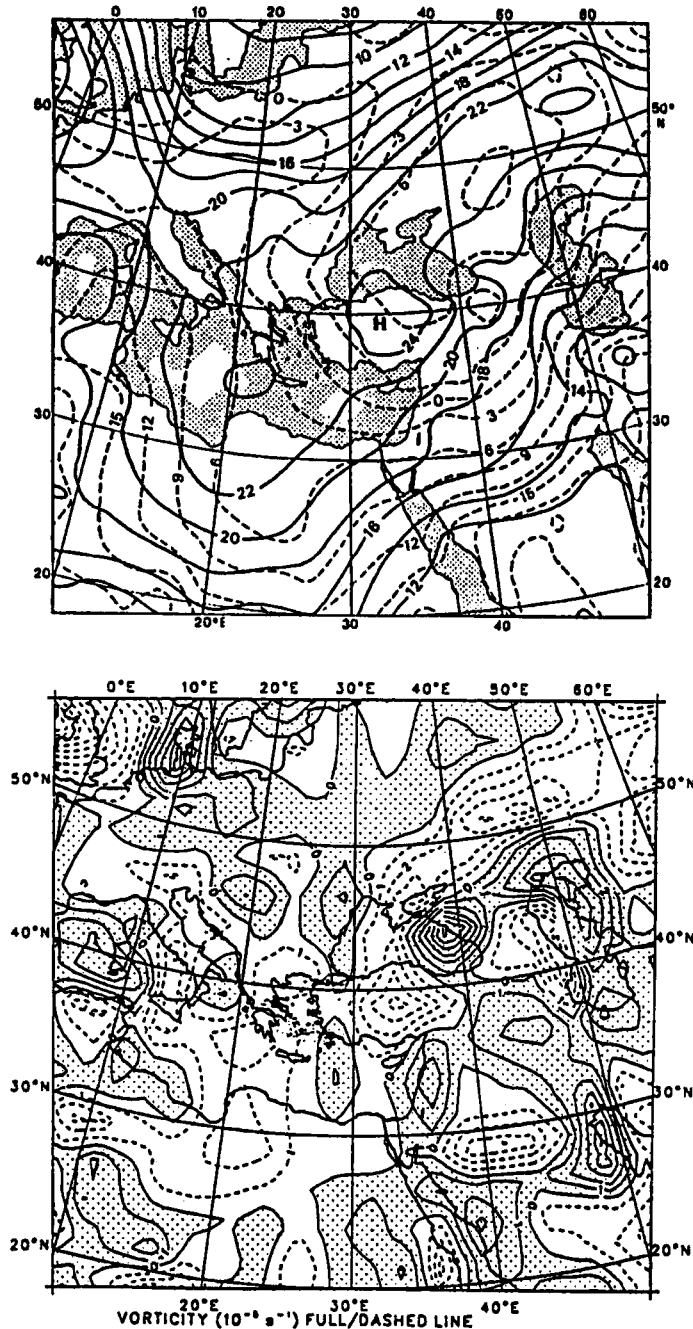


Figure 4. (a) As in Figure 2(a) but for 13 November 1988. (b) As in Figure 2(b) but for 13 November 1988

Table I represents the vorticity separation for the 72 days, demonstrating that continental polar outbreaks over point C are more common with positive vorticity values, i.e. with cyclonic flow. Negative (anticyclonic) vorticity is found mostly in the north and east of the region, whereas the Levant and eastern Mediterranean regions are under cyclonic flow associated with the Red Sea trough. Examples are presented next by vorticity maps for the 1000 hPa level. The dotted area represents the positive vorticity area and the undotted represents negative vorticity areas, the lines are isovorticity lines in  $10^{-5} \text{ s}^{-1}$  units, with an interval of 1 unit.

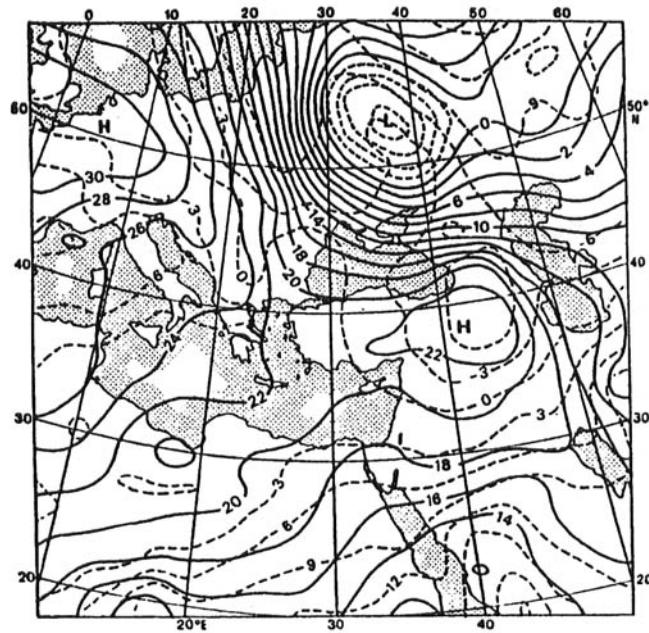


Figure 5. As in Figure 2(a) but for 31 December 1988

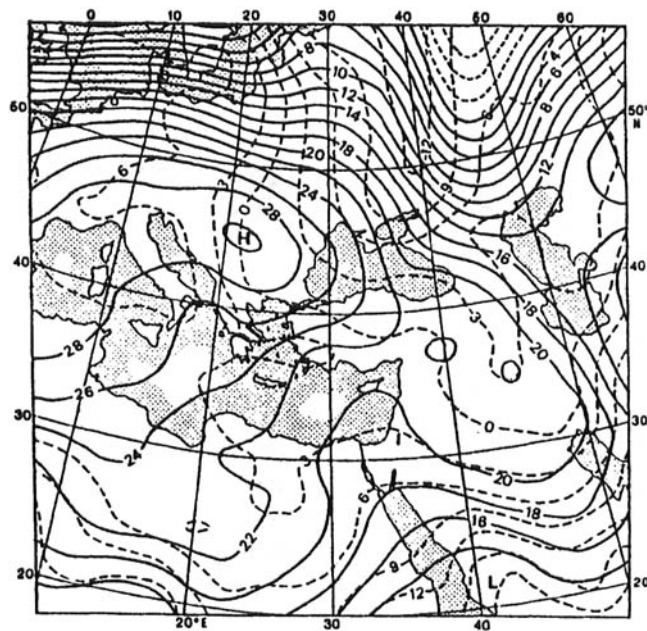


Figure 6. As in Figure 2(a) but for 3 December 1986

The map for the 16 December 1986 (Figure 2 (b)) represents a clear negative vorticity over the eastern Mediterranean, the Levant region, Turkey and the Caucasus. The map for 3 March 1985 (Figure 3 (b)) represents negative vorticity over most of the eastern Mediterranean basin, extending to eastern Turkey, the Caucasus, and northern Asia, but positive vorticity over the centre of the Levant region. The map for 13 November 1988 (Figure 4 (b)) indicates a clear positive vorticity over the Levant region and the eastern Mediterranean. The positive vorticity areas over the southern Levant are attributed to the penetration of the Red Sea trough. Nevertheless, in Figures 3



Table I. Vorticity separation on polar outbreak days

	Positive	Negative	Insignificant at point C	Total
Number of days	48	19	5	72
Relative frequency (%)	67	26	7	100

Table II. Average barometric pressure at Bet-Dagan on polar outbreak days compared with the monthly average (1200 UTC)

Month	Average pressure (hPa)	Standard deviation	Monthly average pressure (hPa)
January	1018.6	$\pm 2.3$	1011.0
February	1015.7	$\pm 1.7$	1011.1
March	1019.0	$\pm 2.2$	1009.0
November	1016.6	$\pm 2.2$	1010.9
December	1017.7	$\pm 2.7$	1011.3

(b) and 4 (b) a disconnection can be seen between the two centres of positive vorticity, one over the Levant region and the other to the south, associated with the Red Sea trough. This situation seems to reflect a local topographic effect over the centre of the Levant region, which might be due to the effect of the Jordan valley, rather than a real penetration of the Red Sea trough. Accordingly, such a situation may be called an 'apparent Red Sea trough' to indicate the disconnection between the two different centres of positive vorticity.

Because the region is influenced intermittently by two different systems, a trough and a ridge, a barometric pressure analysis can be one indicator for the characteristics of continental polar outbreaks.

#### 4. BAROMETRIC PRESSURE COURSE

Barometric pressure is a characteristic feature of the synoptic system. Nevertheless there may not necessarily be a direct relation between the barometric pressure and climatic features of the synoptic system, which are influenced by other factors such as the origin of air mass, temperature and humidity distribution, and pressure gradient.

Barometric pressure data for the 72 days of continental polar outbreaks were taken from the Israel Meteorological Service station at Bet-Dagan (situated on Israel's coastal plain) at 1200 UTC and compared with the monthly average pressure at the station (Table II). It should be noted that Bet-Dagan is situated near the border of the synoptic systems responsible for continental polar outbreaks, as illustrated by the vorticity maps. Hence, the eastern and inner regions are affected more significantly by the polar outbreak phenomena than Bet-Dagan. Table II shows that the barometric pressure, during continental polar outbreaks, is higher than the monthly average, despite the strong influence of the Red Sea trough during most of the events.

Analysis of the barometric pressure course during these events showed that a tendency towards pressure increase begins 2–3 days before the easterly flow is established. This tendency exists mostly during the beginning of the event (generally during the first and second days), while pressure drops develop in the course of the easterly flow. Therefore, it can be concluded that the process of pressure increase precedes the continental polar outbreak and lasts only for the beginning of the event.

Figure 7 represents the barometric pressure course of five events, at the Bet-Dagan station (12 UTC), from the fourth day before the beginning of the easterly flow, until the end of the event. All curves emphasize the tendency of pressure increase a few days before the beginning of the polar outbreak, and during its first stage.

Figure 8 (a and b) represents the average barometric sea-level pressure variation and average isohypsic 850 hPa height variation for Bet-Dagan at 1200 UTC. It covers the period from the third day preceding the outbreak to the end of the event. It also represents the frequency of pressure and isohypsic height increase in per cent. This analysis includes 30 events, covering a total of 72 days. It reflects a pressure increase tendency preceding the outbreak and during its first days, and a decrease along the rest of the period.

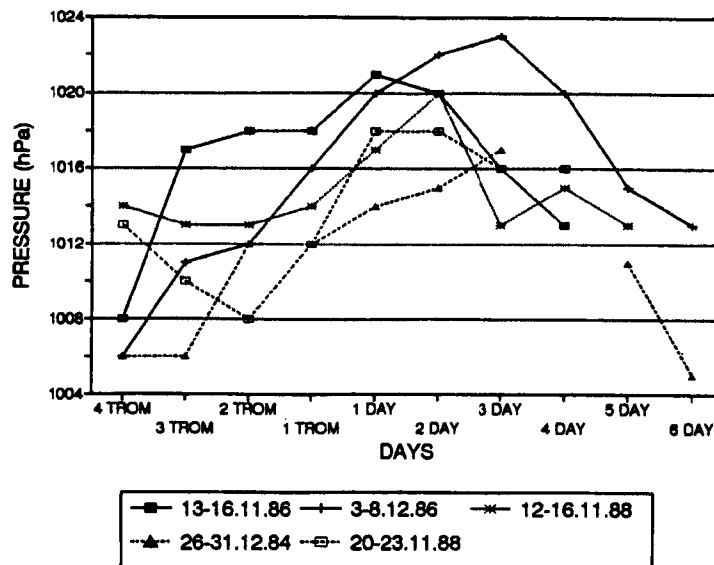


Figure 7. The barometric pressure course of five events, at Bet-Dagan station, 1200 UTC, from the fourth day before the beginning of the easterly flow until the end of the event

The above results lead to the conclusion that the anticyclone, influencing the region, weakens during the continental polar outbreaks, thus explaining the typical positive (cyclonic) vorticity found above. Therefore, one can conclude that events beginning with anticyclonic vorticity change into cyclonic vorticity quite early in the course of the continental polar outbreaks probably due to the effect of the Red Sea trough.

## 5. MONTHLY VARIATION OF FREQUENCY

The Eurasian anticyclones are developed most during the cold season. (Air Ministry Meteorological Office, 1962; Lydolph, 1977; Takahashi and Arakawa, 1981), thus it is expected to find more days of continental polar outbreaks during the coldest period—January and February. The Bora and Mistral winds, associated with continental polar outbreaks in Europe, have their highest frequency during December–March (Air Ministry Meteorological Office, 1962). Table III shows the monthly distribution of continental polar outbreak days. The highest frequency is found in December, followed by January and November. February and March have lower frequency rates, with the lowest being in October. These outbreaks were not found during the months of April–September.

This frequency decrease from December until February can be related to several factors. Turkey and the north-eastern Levant regions respond rapidly to the minimum sun radiation in December. Therefore, the maximum cooling in these regions is during December and January, leading to the build-up of the strongest and most frequent thermal anticyclones during these months (Lydolph, 1977).

Research on cyclone trajectories in the eastern Mediterranean basin (Alpert *et al.*, 1990b) suggests a fluctuation in the cyclone trajectories for the above reasons. In December, the average trajectory is more towards the southern part of the Mediterranean basin. During the later winter months the trajectories tend northward, toward Turkey. Therefore, more southerly cyclone trajectories during December are associated with more frequent occurrences of anticyclones over Turkey.

Another analysis of the above tendency was made on the basis of a monthly average horizontal wind on the east–west axis—the  $u$  wind component. Figure 9 (a–c) features  $u$  for the winter months of December–February, at the 1000 hPa level. The data are a 6-year average, 1983–1988, for 0000 and 1200 UTC from ECMWF system data on a horizontal grid of  $2.5^\circ \times 2.5^\circ$ . Positive values represent westerly winds and negative values represent easterly winds (negative values are dotted). The magnitude of the wind-vector arrows represent 10 hours displacements.

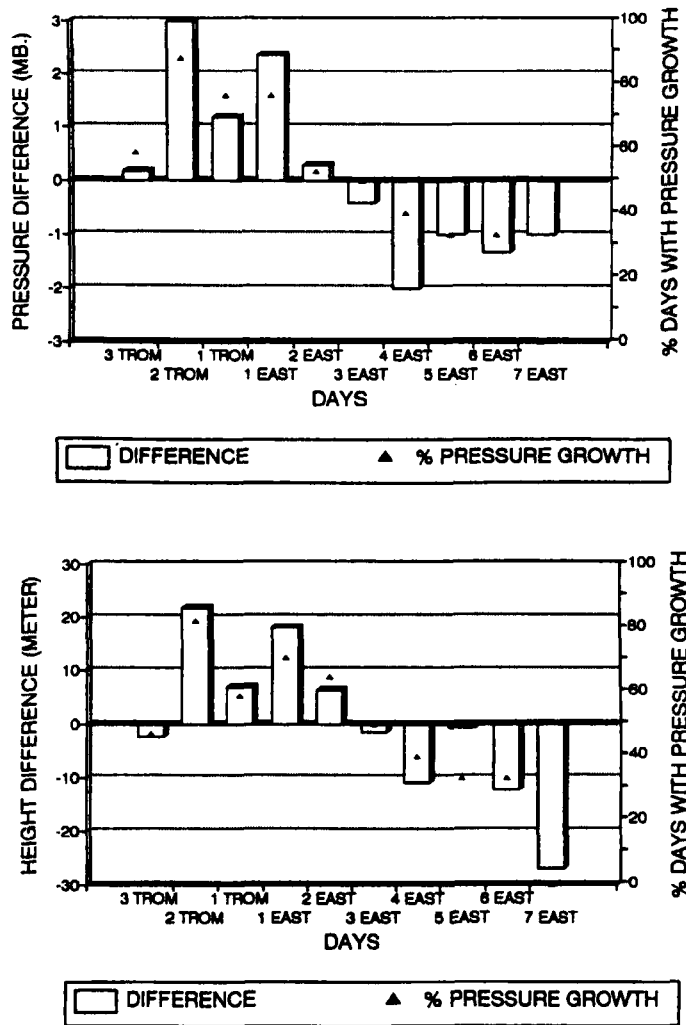


Figure 8. (a and b) The average barometric sea-level pressure variation and the average isohypsic 850 hPa height variation, respectively, for Bet-Dagan, and the frequency of pressure and isohypsic height increases in per cent, 1200 UTC

Table III. Monthly distribution of continental polar outbreak days

Month	January	February	March	April	May	October	November	December	Total
Number of days (1983–1988)	13	8	7	0	0	3	13	28	72
Monthly relative frequency (%)	18	11	10	0	0	4	18	39	100
Average number of days per month	2.2	1.3	1.2	0	0	0.5	2.2	4.6	12

The following trends are demonstrated in these maps.

- (i) Turkey and the north-eastern corner of the Mediterranean basin are under the influence of the easterly flow, whereas the Levant region and most of the eastern Mediterranean basin are influenced by the westerly flow. It indicates that the westerly wind component increases from north to south. This favours easterly flow events over the northern part of the region, and thus higher frequency of continental polar outbreaks there.

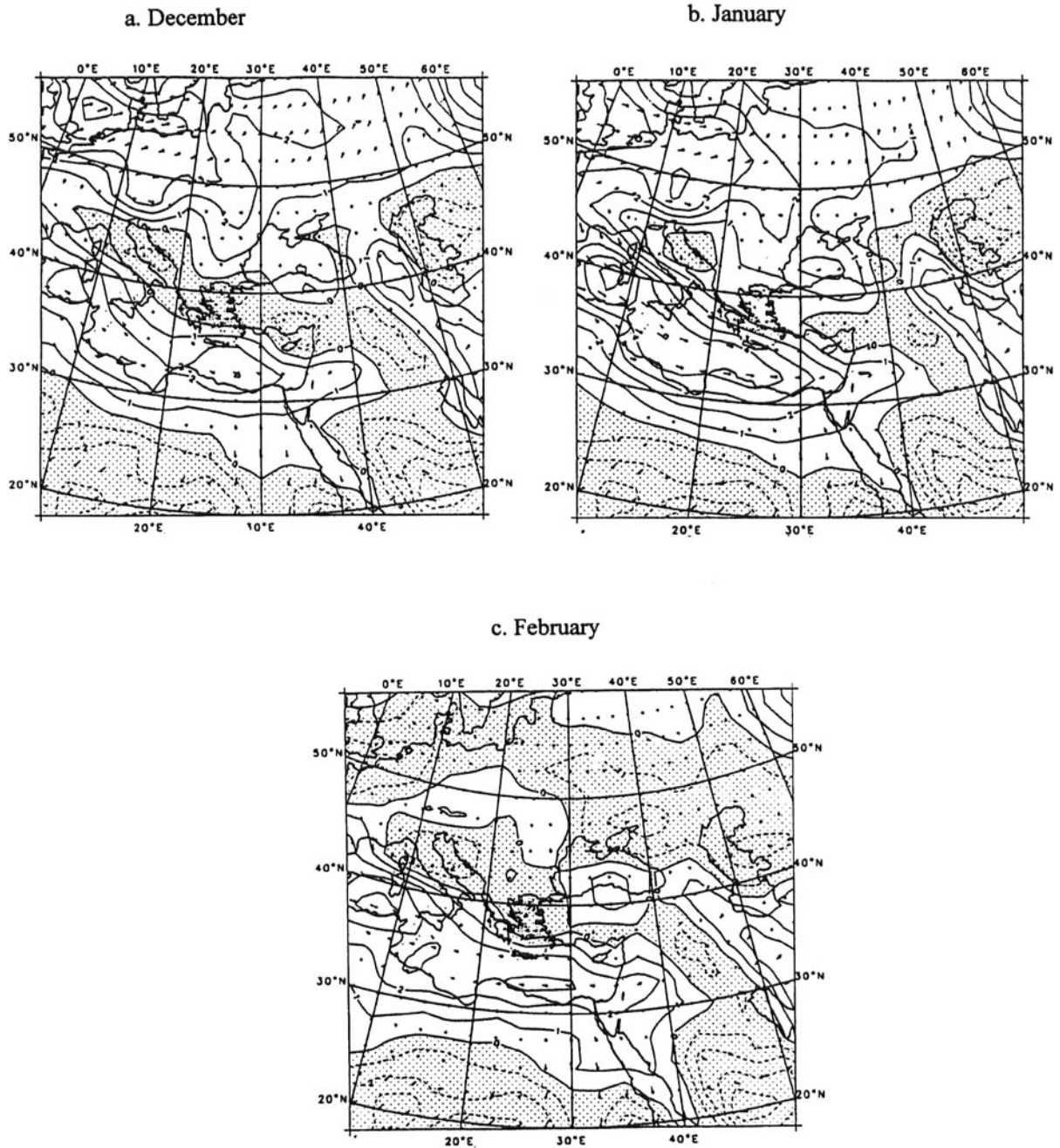


Figure 9. (a–c) The mean  $u$  wind component for the winter months. December–February, at the 1000 hPa level, 0000 and 1200 UTC; the wind velocity interval is 1 m s<sup>-1</sup>, negative values are dotted

- (ii) Easterly flow decreases from December up to February. During December, the easterly flow extends west of Italy and the centre of Cyprus. During January and February, the extent of the easterly flow diminishes at the Levant and in the Turkish region.

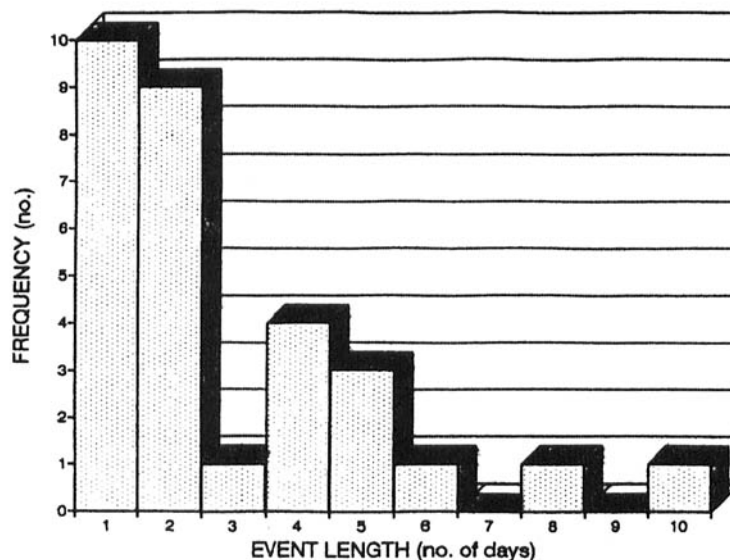


Figure 10. Distribution of the length of the 30 events

A similar trend has been found for the 850 hPa level, with two exceptions:

- (i) westerly component flow is dominant at the 850 hPa level in regions where the easterly flow appeared at the 1000 hPa level, due to the reduction of topographic constraints and weakening of the anticyclone with height;
- (ii) wind velocity at the 850 hPa level was stronger because boundary layer friction nearly vanishes.

In summary, there is a tendency for a decrease of easterly flow from north to south and from December until February.

Despite the above analysis, the relatively high frequency of events during March is unusual when one considers the synoptic situation characterizing this month. The relatively high frequency of events during March may be the result of an exceptional event where a continental polar outbreak lasted for 6 days (1 March 1985 to 6 March 1985). It should be noted that another such event occurred in March 1990, and an easterly storm in March 1992 began with a continental polar outbreak. These events lasting for only 1–2 days.

## 6. PERSISTENCE OF CONTINENTAL POLAR OUTBREAKS

The persistence of continental outbreak was defined according to the number of successive days with both easterly flow and temperature lower than the monthly average at the 850 hPa level.

The 72 days of continental polar outbreaks were distributed over 30 events, lasting for 1–10 days. Average duration is 2.9 days, with a standard deviation of 2.2. Distribution of the duration of the 30 events is illustrated in Figure 10. It indicates two categories of events: the short, lasting for 1–2 days, and the long, lasting for 4–5 days. The most common is the short category.

A subjective synoptic analysis of the continental polar outbreaks showed that there are two typical scenarios of termination.

- (i) Gradual veering of easterly flow into south-easterly flow, followed by a continental tropical air intrusion, and consequent warming. This change is connected with the Red Sea trough penetration into the Levant region, at lower atmospheric levels. At the same time, middle and high troposphere levels are under subsidence, associated with warming and drying. Figure 11 (a and b) illustrates that this kind of termination occurred between 13 January 1983 and 14 January 1983 (0000 UTC).

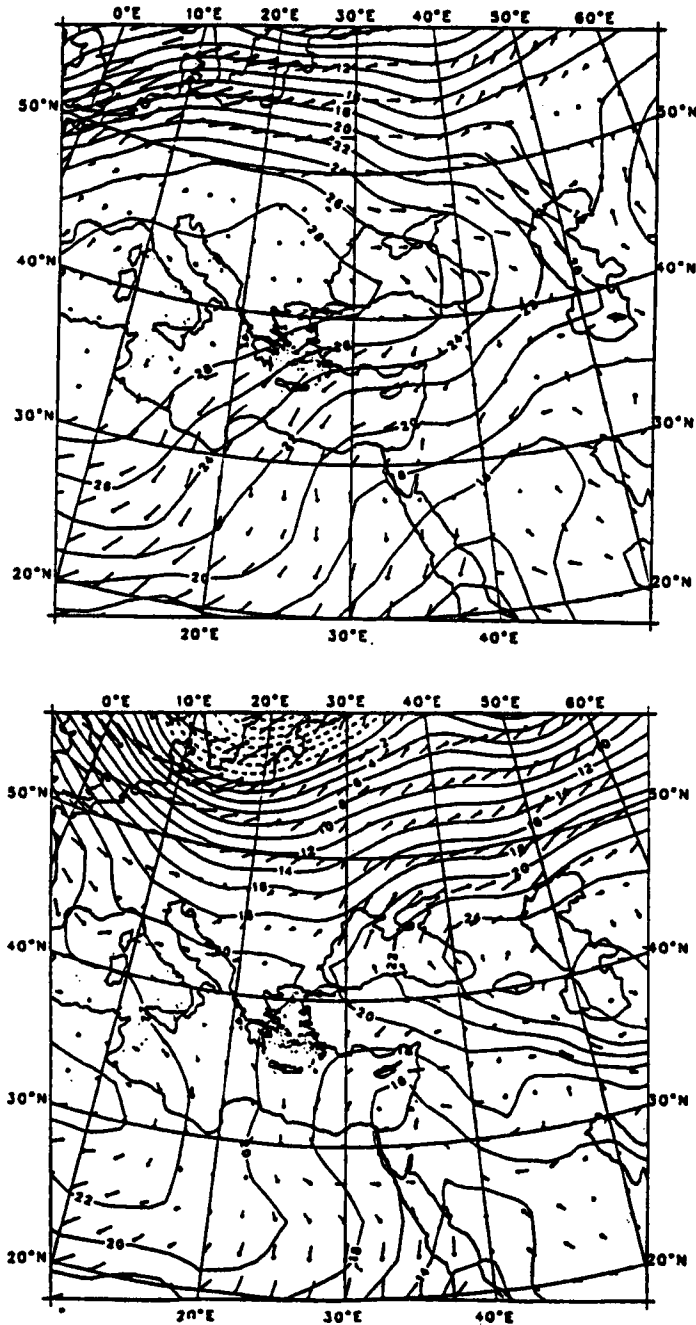


Figure 11. (a) 1000 hPa height for 13 January 1983, 0000 UTC, height interval is 1 dam. (b) As in (a) but for 14 January 1983

- (ii) Progression of a frontal cyclone, from the Mediterranean Sea or North Africa, causing a relatively sharp flow change, firstly into a south-easterly and then into a south and south-westerly flow, associated with an approaching warm front. The change is from a quasi-steady system into a system connected with a travelling Rossby wave. The system may be a cold one, such as the Cyprus cyclone (Alpert *et al.*, 1990a), or a north African cyclone, known as the 'Sharav' cyclone (Alpert and Ziv, 1989). Consequently, continental tropical air

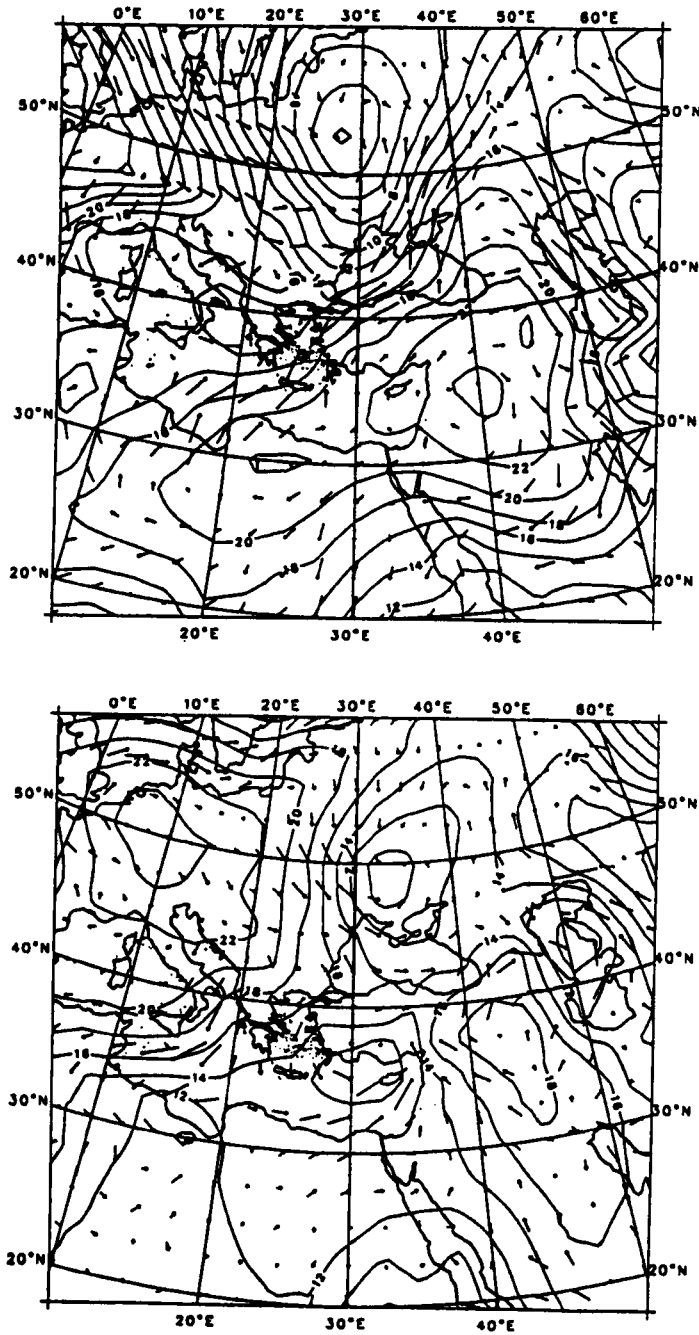


Figure 12. (a) As in Figure 11(a) but for 14 November 1988, 1200 UTC. (b) As in (a) but for 16 November 1988, 1200 UTC

masses penetrate into the region. These are known as the 'Shirocco' and 'Khamsin' winds in the Mediterranean basin (Air Ministry Meteorological Office, 1962). Figure 12 (a and b) illustrates that this kind of termination occurred between 14 November 1988 and 16 November 1988, 1200 UTC. On 14 November 1988 the Levant region was influenced by a Caucasian anticyclone, whereas on 16 November 1988 there was a flow change to south-easterly flow due to the warm front of a Cyprus depression.

## 7. CONCLUSION

The Levant and eastern Mediterranean regions, characterized by the complex Mediterranean climate, are subject during the cold season to spells of continental polar outbreaks. Meteorological research of the Levant and eastern Mediterranean regions recognizes the synoptic situation of continental polar outbreaks as a 'Siberian anticyclone' (Koplowitz, 1973; Elbashan, 1977; Ronberg, 1984; Rosenberg, 1987; Lieman, 1990; Shafir *et al.*, 1994). Such a name seems not to fit the above analysis. Synoptic definitions of these outbreaks should emphasize weather conditions—cold, dry, and stable weather caused by continental polar outbreaks, originating from large continental regions north and east of the Levant and eastern Mediterranean regions, in Asia and Europe. Thus, the appropriate name should be 'Polar ridge' instead of the more limited concept of a 'Siberian anticyclone'. Nevertheless, vorticity analysis shows the dominance of cyclonic flow, with positive vorticity over the Levant region. Therefore, the barometric ridge is most commonly located north of the region, mostly in Turkey, the Caucasus, northern Asia, or eastern Europe, while the Levant regions seems to be influenced by the Red Sea trough with cyclonic flow. The course of barometric pressure in Bet-Dagan, Israel, indicates that pressure rise begins 2–3 days before the cold outbreak initiation and lasts during its first days. During the rest of the period, usually after the second day, there is a tendency of pressure to decrease. Hence, there is a weakening of the polar ridge from the beginning of the event, a fact that is consistent with the high percentage of cyclonic vorticity. Thus, events beginning with anticyclonic vorticity, change into cyclonic vorticity during the continental polar outbreak and the easterly flow.

There is a specific seasonal dependence of the frequency occurrence, with events occurring between October and March only. The highest frequency was during December, with a decreasing tendency towards the other months. This tendency seems to be associated directly with changes in the cyclones trajectories, and to a change in the pressure gradient between the anticyclone over Asia and Turkey and lower barometric pressure over the Mediterranean. The typical duration of these events was of two categories: short events of 1–2 days, and long events of 4–5 days. Termination of these events is characterized by two typical patterns, flow change into south-easterly direction, causing continental tropical outbreak despite a persistence of 'quasi-stationary' system, or the advance of a frontal cyclone.

In conclusion, continental polar outbreaks create unique weather conditions that have vast environmental implications for the Levant and eastern Mediterranean regions and are associated with different synoptic patterns and a specific seasonal dependency of occurrence.

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