An Early Winter Polar Air Mass Penetration to the Eastern Mediterranean

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28 December 1983 and 13 December 1985

ABSTRACT

A deep polar air-mass penetration to the eastern Mediterranean in November 1982 is described. The unusual weather and, in particular, the rain pattern is discussed. This event contributes to heavy rain in the inland stations, of particular importance in the semiarid zone.

The stability characteristics of the polar air mass on its way to the eastern Mediterranean are investigated and compared to a similar case in the western Mediterranean. It is suggested that the land-sea distribution along the path of the penetrating polar air mass is responsible for the significant differences that were found.

1. Introduction

The first study of deep polar air-mass penetration to the subtropical region is probably that by Palmén (1949). Other studies by his group investigate further cases of "cutoff" lows and their synoptic characteristics over North America. Simpson (1952) analyzed a similar case over the eastern Pacific near Hawaii and named it a "Subtropical Cyclone." Two of the most prominent features in regard to those subtropical cyclones is their relatively long persistence—sometimes more than a week—and the special weather associated with them. Ramage (1962, 1971) explains their long persistence by their energy-exporting character and the insignificant effect of surface friction. In Ramage's (1971) suggested model for the subtropical cyclone, the fields of motion, clouds and weather are symmetrically distributed in contrast to the heavy precipitation associated with a trough which is generally concentrated east of the trough axis.

In this work, we are concerned with a subtropical cyclone in the eastern Mediterranean. It will be shown that the special path of the polar air mass to that area leads to an abrupt change in its stability characteristics when penetrating the eastern Mediterranean. In comparison, a similar case study at the western Mediterranean is also analyzed and does not show this abrupt change. In view of that result, it is suggested that the study of a Subtropical Cyclone cannot be separated from its formation process and, in particular, the land–ocean characteristics along the path of the polar air mass to the subtropical region.

Such occasions, which are not unusual during winter in the eastern Mediterranean, are rare in the very early winter and the unstable stratification generated by the presence of the warm Mediterranean waters causes heavy precipitation. The rainy weather, which persists a whole week in the beginning of November in many areas of Israel, supplied as much as 20% to 30% of the total annual precipitation at a time when the climatological rainy season had scarcely started. As will be shown, such an event makes a very important contribution, if not the major one, to the total rainfall in the semiarid zones of the region.

2. The weather associated with a polar air-mass penetration to the Mediterranean Sea region

This work focuses on the week of 6 to 12 November 1982, in which very cold air had penetrated the eastern Mediterranean. Figures 1a–e present the series of 500-mb maps at 0000 GMT in the region for 6–10 November. The rain in the eastern Mediterranean had already started on 7 November and was followed by a whole week of rainy weather with only some short intermissions, especially in the more southerly areas. The climax of the rainy weather over the area (in particular for Israel) was on 8 and 10 November when the heavy precipitation reached the most southern and desert stations in Israel, e.g., Eilat at ~30°N latitude on the Red Sea Coast. It could also be noticed that on 9 and 10 November, the cold air reached the southern part of the eastern Mediterranean with temperatures of around −25°C at 500 mb. The SST (sea surface temperature) for the region was 21° to 23°C. [The SST reported at Gaza for 6 November was 21°C by the Israel Meteorological Service—not very far from the annual maximum of ~27°–28°C. (See Atlas of Middellandse Zee 1957.)]

The tropospheric static stability above Bet Dagan—station No. 40179—during that week at 0000 GMT is

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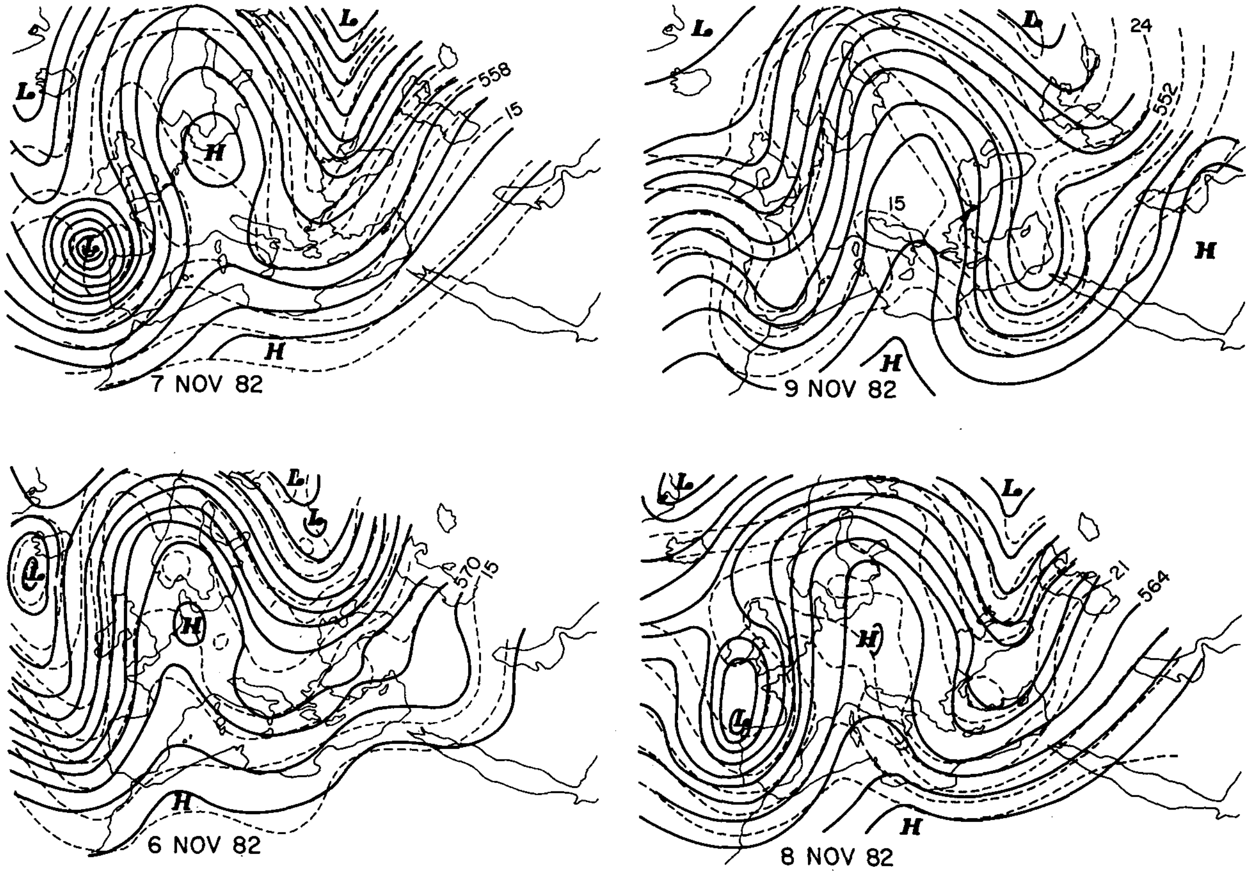


FIG. 1. A series of 500-mb contours for 6–10 November 1982 at 0000 GMT. The full lines represent the isohypses by intervals of 60 meters and the dashed lines are for isotherms by intervals of 3°C. The data are from the IMS (Israel Meteorological Service).

illustrated in Fig. 2. The temperature difference between 850 and 700 mb and also for 700 to 500 mb is shown for 6–13 November 1982 at 0000 GMT. The rainy week is characterized by an average lapse rate of 6.6°C km^{-1} from 850–700 mb, a value fairly close to the pseudoadiabatic value. The stability in the higher layer is not as uniform as in the layer below but rather more scattered and on the average more stable. November 9, which represents the climax of the weather, is the most unstable, while 13 November indicates a sharp increase in the static stability associated with a significant transition to clear weather.

The precipitating clouds during the week were mostly towering cumuli which rarely turned into a thunderstorm; see Fig. 3. The rainy cumulus clouds penetrated deeply to the semiarid zone and covered nearly all the Sinai Peninsula. All of the satellite photographs during that week were similar, in that large areas of the southeastern Mediterranean were covered by rainy clouds.

The amounts of precipitation (in millimeters) reported at 24 stations in Israel for that week, along with average seasonal accumulation for the end of the week, percentage of actual relative to the average seasonal, and also the average annual precipitation are summarized in Table 1. The rainy season in Israel is the winter and the actual accumulated precipitation on 13 November is nearly the same as the total precipitation for that week, because almost no stations had reported seasonal rain before that event. Figure 4a shows the histograms for the percentage of actual precipitation during the week as compared to the seasonal average (shaded area) and both relative to a scale by which 100% represents the average annual precipitation at each station. The stations are numbered from north to south, and their geographical location is given in Fig. 4b. Contours of the percentages of actual to seasonal averages are also drawn. As can be seen, nearly all stations received more precipitation during that one event than the average seasonal accumulated for that time. Most of the stations received approximately double the average seasonal accumulation (some as high as 300%—e.g., stations 16, 23 and 24). Stations which got very high values are either mountainous—Hebron (21): 270%; Schem (16): 330%—or in the semiarid zone—Beer Sheva (24): 338%; Besor (23): 292%. Mountainous

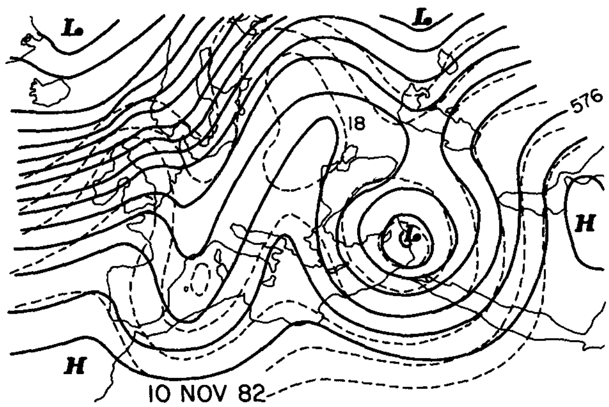


FIG. 1. (*Continued*)

stations got high values because the rain clouds probably persisted at the higher elevations owing to orographic effects, while the semiarid stations indicate high percentage values because of the relatively low total average value of precipitation there. This is also in agreement with the high variability of precipitation at the semiarid regions (e.g., see Katsnelson, 1964).

The precipitation pattern in Fig. 4a indicates the following interesting feature of the present synoptic situation: while the average percentage shows high values at the coastal stations—numbers 2, 4, 9, 10, 11, 12, 22, this event gave more precipitation (relative to seasonal norm) at inland stations. This is interesting because usually the early winter is characterized by rain deficiency at inland stations, which is replaced later by an excess in mid-winter as the sea–land contrast effect diminishes relative to that of the orography (see Elbashan, 1966.)

A possible explanation is that, owing to the persistence of the present system for the whole week, the land–sea contrast effect was diminished appreciably during the week in spite of its occurrence in the very early winter. Also, due to the deep penetration of the cold air, the inland topography and the inland temperature contrasts played a more important role than in common November storms.

Another interesting fact with regard to this event is the report of snow in Baal-Hatsor (a station near Jerusalem at a height of 1016 m) on the night of 10 November. The surface temperatures were as high as 3°C and the snow could not accumulate. However, this is a November record, as snow events in the winter season have never been reported in Israel before 22 November. Only two November snows were recorded in Jerusalem (1908 and 1953) and those cases were at the end of the month. (See Batz, 1981; Bitan and Ben-Ruby, 1978.) The winter of 1982/3 is also outstanding in the number of snowy days in Jerusalem, with ten snow events reported (for a total of seventeen snowy days) while the average is only 2.3 snowy days per year. Most of the past snow events in Jerusalem have been in February when the Mediterranean SST reaches its minimum value. The unusual winter of 1982/3 was noticed in other places over the globe and, especially, we note the very strong El Niño at the coast of Peru and the very stormy weather reported above the West Coast of the United States. Rasmusson and Hall (1983) state, in referring to the El Niño's sea surface temperature anomalies for 1982/83, that "these anomalies far exceeded anything previously recorded." The relation between Jerusalem snow occurrences and El Niño events was recently established in a study in which data for more than eighty years for these two infrequent events were compared and found to be highly correlated (not yet published).

3. Deep polar air-mass penetration in the eastern and western Mediterranean

As already noted, special attention will be given here to the unique modification of the polar air mass penetrating the eastern Mediterranean. Another case of deep penetration in the *western* Mediterranean happened to occur just one week after the previous event. Figures 5a–c present a series of 500-mb maps at 0000

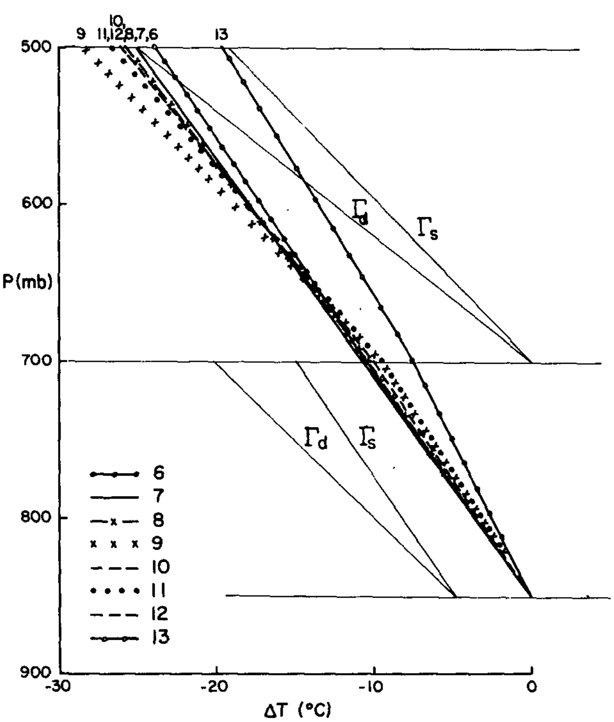


FIG. 2. The temperature differences ΔT between 850 and 700 mb and (top) the ΔT for 700–500 mb plotted for 6–13 Nov. 1982 at 0000 GMT. Different curves represent the various days. Notice that 10 and 12 are represented by the same curve. The average moist and dry adiabats at both layers are indicated by Γ_s and Γ_d.

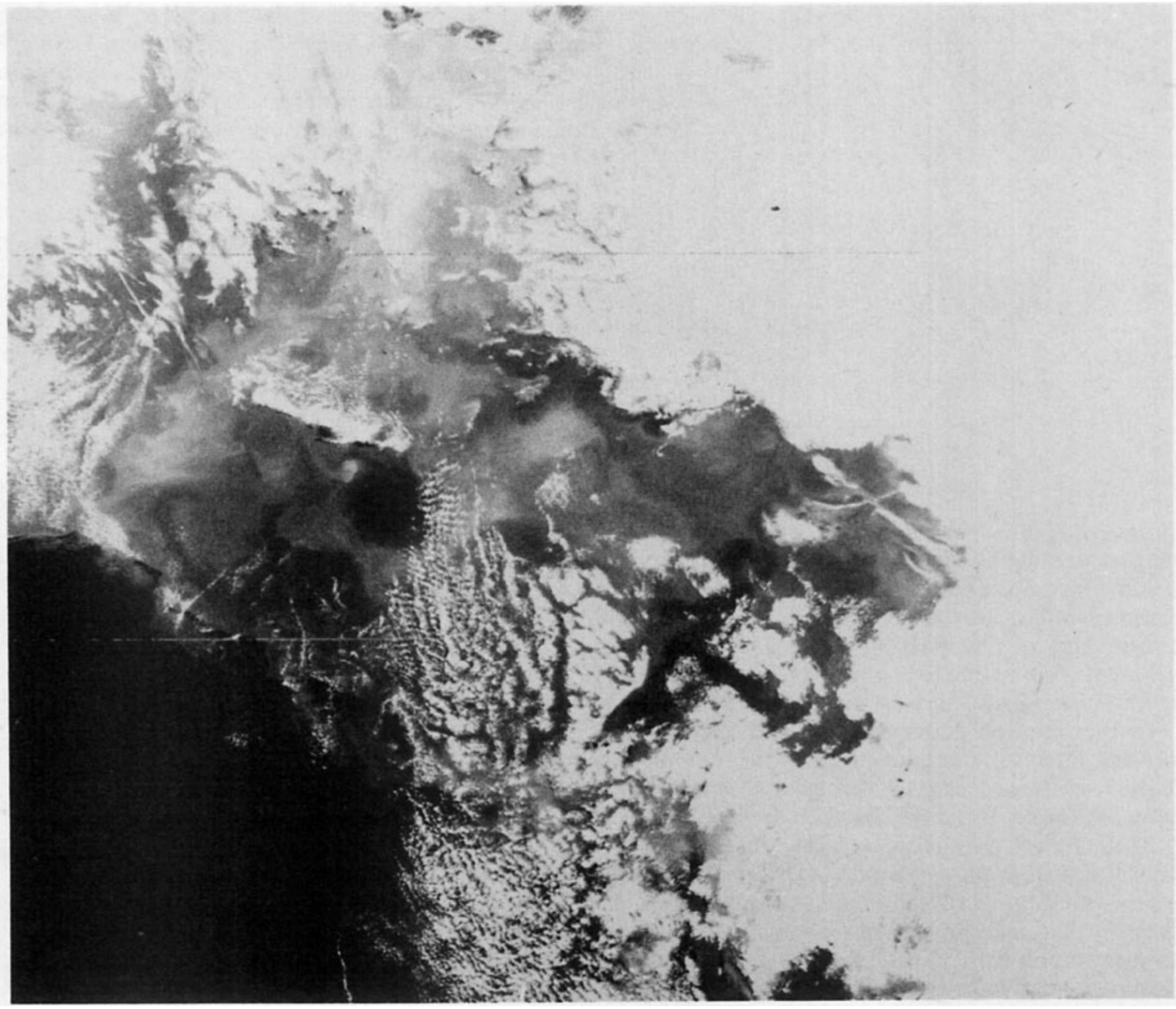


FIG. 3. The infrared (IR) photograph by NOAA 7 at 1229 GMT 10 November 1982, for the eastern Mediterranean. Most parts are cloud-covered in the southeastern area but Cyprus and the southern part of the Red Sea may be noticed.

GMT for 14 to 16 November 1982 which precede the formation of a "cutoff" low west of Corsica, accompanied by relatively cold air. Of course the term "cutoff" should not be taken literally as the low is not really cut off from the northern trough. Cold air may still be supplied through sloping convection. In this event, temperatures of −30°C at 500 mb were reported above the Mediterranean. The station of Alger (Dar el Beida, synoptic No. 60390) at the coast of Algeria reported −29°C at 500 mb and was chosen for the following study. It is important to note that such occasions are more frequent in the western Mediterranean than for the eastern and are probably predominantly the result of Alpine and Piranine lee cyclogenesis as discussed, for example, by McGinley (1982). Also, note that such a penetration is not as deep as in the eastern Mediterranean because the western Mediterranean is located farther to the north (latitude of 35°–40°N).

Nevertheless, we traced the cold air mass by looking for temperatures lower than −25°C both at the eastern and western events. Figure 6 presents the −25°C isotherm at 500 mb for I, II, III, etc., days preceding the reported event of −25°C above the eastern Mediterranean at 0000 GMT on 10 November. In the western case, only two days of tracing back from 16 November at 0000 GMT were possible since at day III, the air mass was over the ocean. As the past location of the polar air mass was impossible to define accurately, some stations in each region were chosen along the approximate path of the polar air mass. The average temperature at 850, 700 and 500 mb for each of these stations was assumed to be representative for the past temperature of the polar air mass at the pertinent chart. Of course, the slant-wise convection necessary for the baroclinic disturbance (e.g., Holton, 1979) may have a significant influence on the temperature distribution

TABLE 1. The amounts of precipitation (in millimeters) reported at 24 stations in Israel. First row is for the average seasonal accumulation and the second row is the actually accumulated rain (for the year 1982) until 13 November. The third row is the percentage of actual to seasonal average and the last row is the yearly average rain accumulation at each station.

Station number	Station name	Average seasonal accumulated rain for 13 Nov (mm)	Actual accumulated rain for 13 Nov (mm)	Percentage of actual to seasonal average (%)	Accumulation of rain in year (mm)
1	Kfar Blum	35	88	254	479
2	Nahariya	63	119	188	601
3	Knaan Mount.	52	100	191	718
4	Shiqmona	52	124	239	508
5	Nazereth	43	67	157	626
6	Degania	30	68	227	384
7	Ramat David	49	92	228	483
8	G. Shomron	52	98	188	597
9	Sede Dov	58	48	83	539
10	Qir. Ono	55	49	89	551
11	Yafo Port	57	41	72	542
12	Beth Dagan	52	65	126	535
13	Ben-Gurion (AP)	48	84	174	513
14	Eqron	45	79	176	489
15	Haf. Haim	44	56	127	465
16	Shchem	44	144	330	618
17	Jerico	12	24	203	144
18	Jerusalem (Center)	33	67	203	486
19	Rosh Zur.	47	64	136	662
20	Bt Jimal	43	64	150	493
21	Hebron	34	93	270	466
22	Gaza	45	50	112	371
23	Besor F.	24	70	292	233
24	Beer Sheva	15	59	388	204

at 500 mb. Consequently, the location of the 500-mb isotherm does not necessarily coincide with that of the air mass. Thus, Fig. 6 represents only the approximate location of the cold air mass based upon the 500-mb temperatures.

Figures 7a, 7b illustrate the modification of the polar air mass stability as it moved toward the eastern and western Mediterranean, respectively. The bottom arrows represent the difference between the actual and the dew-point average temperatures at 850 mb for each region, i.e., $\bar{T} - \bar{T}_d$ (or $\Delta\bar{T}_d$) at the corresponding regions. The temperature differences were derived by averaging the upper air station's data assigned in Fig. 6. As shown, an abrupt change in the average stability is noticed when the polar air mass encounters the eastern Mediterranean. This change is also accompanied by an appreciable increase in moisture. The value of ΔT_d in Beth-Dagan, day zero, is close to zero. It could be noticed how even the Black Sea has slightly modified the average stability of the lower layer, 850–700 mb, but not that of the higher layer, 700–500 mb. This is illustrated by the change from the average sounding No. II, representing the average temperature profile which has followed passage over the Black Sea, as shown in Fig. 6. The eastern Mediterranean thus seems to be responsible for a decrease of stability, particularly

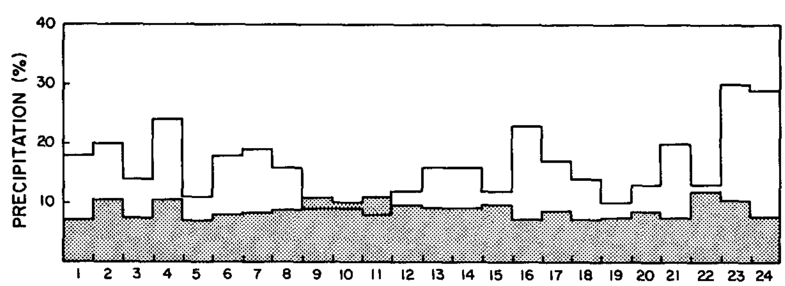


FIG. 4a. Percentages of actual precipitation during the week of 6–13 November 1982 and also that for the seasonal average (shaded area). The percentage is relative to the value of the average annual precipitation for each one of the 24 stations in Israel.

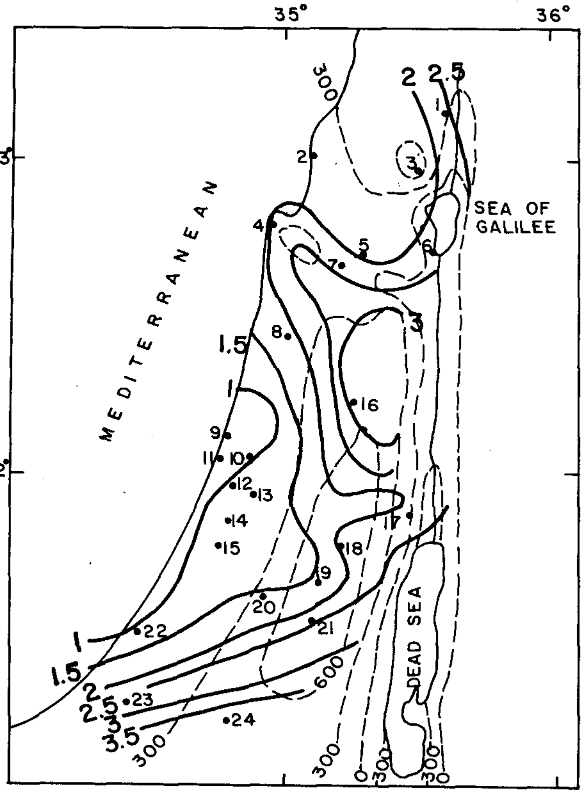


FIG. 4b. A sketch of the area indicating the locations of the 24 stations whose precipitation was decribed in Fig. 4a. Also, contours of percentages of actual to seasonal averages are drawn in hundreds. The dashed lines represent topography contours with 300-m intervals.

in the lower layer. This is in accordance with the conclusion of Sethu Raman (1976) that the depth of the modified air mass due to the advection above the warm sea is proportional to the fetch distance. But, at the western Mediterranean (see Fig. 7b) no significant change of the air mass stability is noticed. It is thus suggested that the distribution of land–sea at the path of the deep penetrating cold air mass may have an important contribution to the characteristics of the "cutoff low." This effect was not emphasized by the aforementioned investigators of the subtropical cyclone.

4. Summary and conclusions

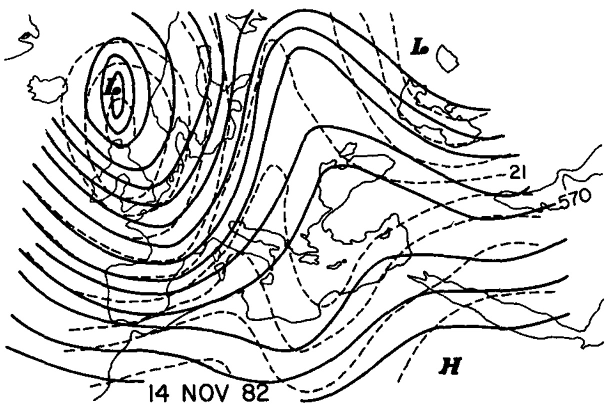
This work focuses on a rather rare occasion of an early winter deep penetration of a polar air mass into the eastern Mediterranean region. The trajectory of the air mass for that event was found to be directed to the north and not, as typical, to the northwest. For typical trajectories of rainy air masses arriving at the Israeli Mediterranean coast, see, e.g., Gagin and Neumann (1974). A similar but less profound case of cold-air penetration at the western Mediterranean was analyzed but no significant stability modification was found, and this is explained by the land–sea distribution at the path of the penetrating polar air mass. This might partly explain the different findings by Ramage (1970) in considering the weather patterns associated with a subtropical cyclone near Hawaii when compared to previous studies.

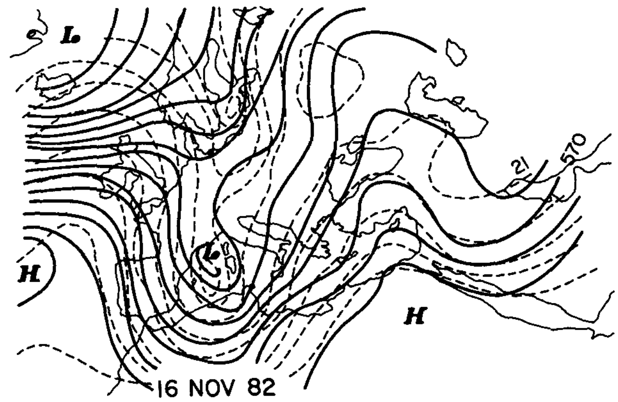
It was also shown that the cold outbreak to the eastern Mediterranean in the early winter had a large impact on the precipitation pattern in Israel, particularly in the semiarid region. Actually most of Israel's rain is associated with the midlatitude migrating troughs which cause cold air masses to penetrate the region. But it is seldom that the penetration is as deep and as long as in the present case and, in particular, this has a large impact when it happens at the beginning of the season. It is difficult to estimate the long-range contribution of such an event to the average annual precipitation because no climatology of this phenomenon exists; nevertheless, it is believed to have a considerable contribution to the rain in the semiarid zone.

The winter of 1982/83 which started with a very early light snow in the Judah mountains and was followed by seven additional snow events in Jerusalem indicates the uniqueness of this year with its frequent cold outbreaks to the subtropical region of the eastern Mediterranean.

One of the important questions concerning this event is in regard to the physical dynamical mechanisms for its formation. The frequent cyclogenesis in the eastern Mediterranean may be partly contributed to by lee effects of the high Turkish mountains. Following the cyclogenesis study in the Alps by Buzzi and Tibaldi (1978), we have also constructed the isentropic cross sections along the air mass path through the Turkish mountains to Israel. Unfortunately, they are not shown here because the data at the lee side of the mountains, which is essential for such an analysis, do not exist owing to the lack of observations above the Mediterranean Sea. Others stress the predominant effect of the low-level supply of heat and moisture above the sea and the subsequent release of latent heat in the presence of static instability. Alpert (1984) has suggested that the CISK (conditional instability of the second kind) may play an important role in the eastern Mediterranean in keeping local depressions present for relatively long periods. This mechanism is significant, especially at the beginning of the winter when Mediterranean SSTs are relatively high.

The relative role of the lee effect and of the CISK, as well as other possible mechanisms for the various depressions in the eastern Mediterranean, will have to await further dynamical studies which will probably have to employ additional surface and upper-air data in the region. Currently we are planning a project of a special observational effort, and a numerical modeling study, aimed at the better understanding of the physical mechanisms of the cyclogenesis in the eastern Mediterranean.





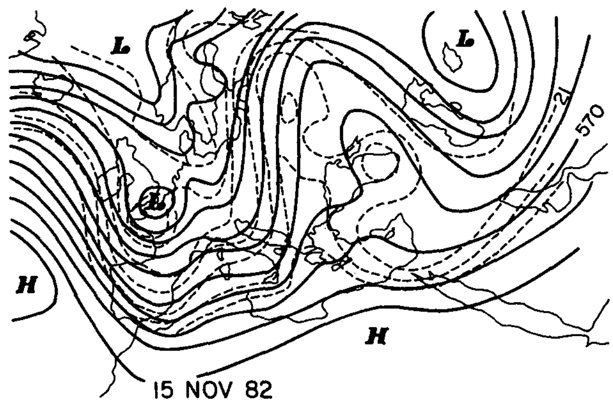


FIG. 5. Same as Fig. 1 for 14–16 November 1982 at 0000 GMT.

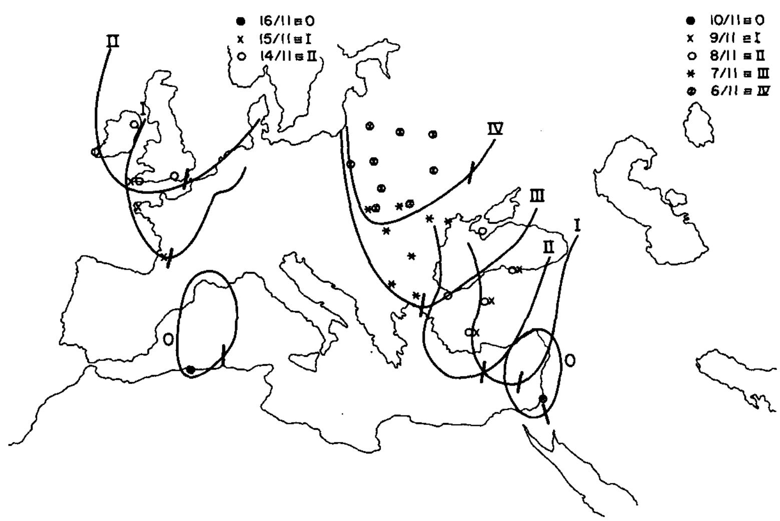


FIG. 6. The geographical locations of −25°C isotherms at 500 mb for 0, I, II, etc. days preceding the reported event of −25°C (−29°C) above the eastern (western) Mediterranean at 0000 GMT 10 (16) November 1982. The points within each isotherm represent the soundings that were available for the study of air mass characteristics. Heavy short lines intersecting the isotherms indicate the locations of the trough for the pertinent lines.

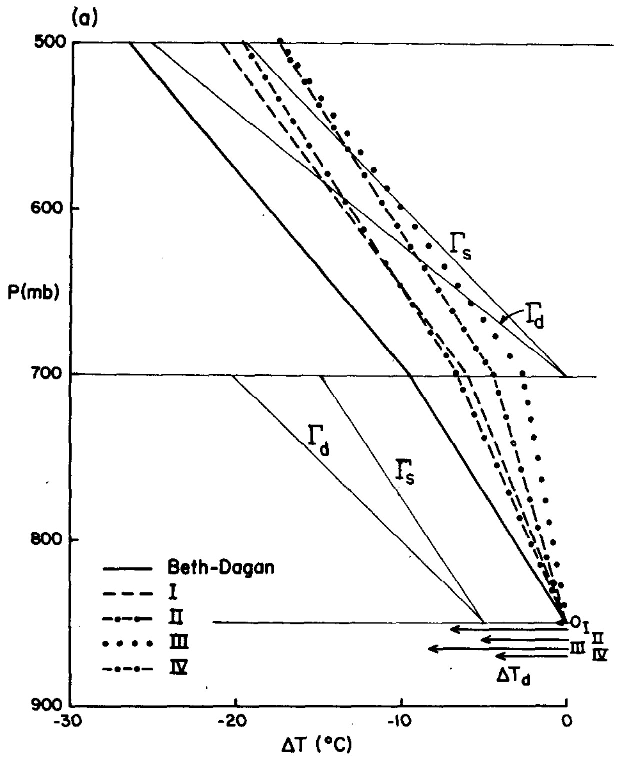


FIG. 7a. The temperature differences ΔT between the average temperatures at the surfaces of 850, 700 and 500 mb for each one of the regions I, II, III and IV. Values of ΔT for 850 to 700 mb and 700 to 500 mb are plotted as function of pressure height. The bottom arrows represent the 850 mb average dew-point depression $\bar{T} - \bar{T}d$ (or $\Delta \bar{T}d$) at the corresponding regions. The average moist and dry adiabats at both layers are also indicated.

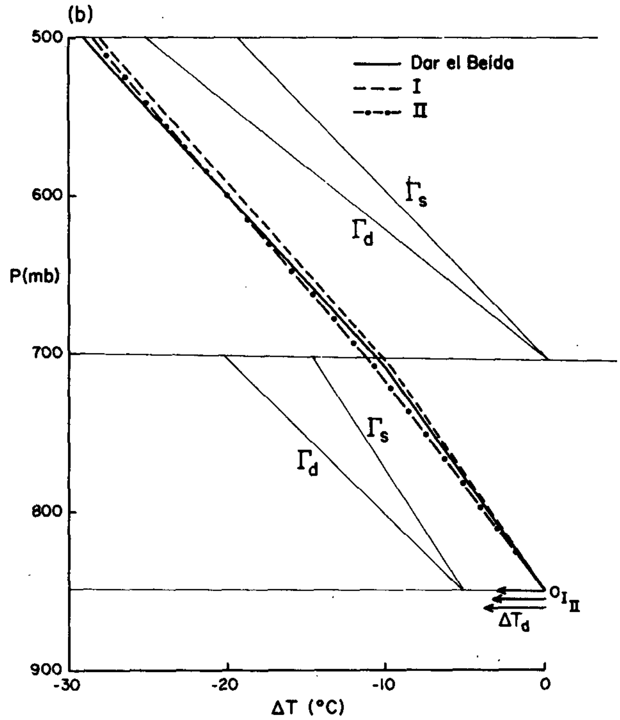


FIG. 7b. As in Fig. 7a for the western Mediterranean.

Acknowledgments. We would like to thank the Cooperative Institute for Mesoscale Meteorological Studies for supporting the research of one of the authors (Alpert). Special thanks to Ms. Kimpel for preparing the illustrations and to Nissim Cohen from the Rainfall Stimulation Branch at the IMS (Israel Meteorological Service) for the rainfall statistics. Thanks to the climatic department in IMS for the maps and data that were provided to us, and to Rachel Duani for patient typing. We would like to express our gratitude to the reviewers for their helpful comments.

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