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Cold small-scale cyclones over the eastern Mediterranean

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ABSTRACT

The lows in the eastern Mediterranean (EM) based on the 1982–86 ECMWF data were classified according to some indicative variables of the low center's surroundings including horizontal scale, temperature, static instability, humidity, surface latent heat flux, baroclinicity and the jetstream location. A quite distinct group of cold meso-α scale (1300 km) cyclones was identified and named the CS (cold small-scale) cyclones. These Mediterranean CS cyclones were found to be characterized by higher-than-average vorticity for cyclones with a similar scale, stronger sea latent heat fluxes but also slightly enhanced baroclinicity and near average low-tropospheric static instability.

1. Introduction

It has been recognized as early as the first satellite pictures that the Mediterranean exhibits hurricane-like storms sometimes even with a distinct storm-eye, e.g., Billing et al. (1983), Ernst and Matson (1983), Rasmussen and Zick (1987). The increased interest in polar lows and their resemblance to tropical storms, see, e.g., Rasmussen (1979), Businger and Reed (1989), raises the question of the character of these small cyclones in the Mediterranean. Alpert (1984) and Alpert and Reisin (1986) suggested that the CISK (Conditional Instability of the Second Kind) mechanism proposed originally by Charney and Eliassen (1964) for tropical cyclones and by Rasmussen (1979) for the polar lows, plays an important rôle in some Mediterranean cyclones.

Since it has recently been agreed that local enhanced convection from warm seas to cold air-masses as well as the large-scale baroclinicity both contribute in different polar lows, see, e.g., Sardie and Warner (1985), it has become of interest to identify their relative rôles in the Mediterranean cold small-scale (hereafter CS) cyclones. In this study, we present an objective analysis of about 200 lows in the eastern Mediterranean (EM) for the purpose of isolating the CS cyclone group. The 1982–1986 ECMWF datasets are employed. Characteristics of these cold and small-scale cyclones, diameter of about 1000 km or less, are described and compared to those of the rest of the cyclones. Focus will be given to the central vorticity, lapse-rate, baroclinicity, moisture layer depth and cyclone location versus the upper level jetstream. Naturally, since the horizontal resolution is $2.5° \times 2.5°$, the study is restricted to scales above about 500 km which unfortunately leaves even the smaller cyclones out of the present analysis.

2. The method

2.1. Data

The initialized 1200 UTC ECMWF data for November 1982–March 1986 were used. Each 1000 hPa geopotential height minimum within the box (30–37.5° N, 30–35° E) generally referred to as the EM region, was identified, see Alpert et al. (1990a). Various calculations have been performed over the 3-D domain around the minimum grid point in order to find the cyclone characteristics. These include grid location, average geopotential height and vorticity at the surrounding points with a gradually increasing distance (up to a maximum of 30° $\sim$3000 kms), in order to define the cyclone scale, (see Subsection 2b). Further output were the location of the jet(s) and wind direction along the longitude of the observed minimum. In addition, we calculated the 9-point averages around each minimum of the following indicative variables:

(i) lower (upper) tropospheric lapse rate, Γ_L (Γ_H), based on 1000–850 (850–300) hPa;
(ii) thickness of the layer with relative humidity above 70% (H_{70});
(iii) temperature at 1000 hPa (T_s) and 500 hPa (T_{500});
(iv) latent heat flux (FQ);
(v) baroclinicity (B); the baroclinicity was estimated by the 850 to 300 hPa wind shear.

The latent heat fluxes were calculated through bulk parameterizations, where the EM sea-surface temperature was interpolated from monthly climatic averages (Reiter, 1975). Each calculation is performed at a single time (1200 UTC daily) for each cyclone. Hence, the life-cycle of the cyclone was not investigated and a cyclone that persists for a successive day is considered as a distinct cyclone.

2.2. Determination of the cyclone scale

One of the most difficult tasks was the objective definition of the cyclone scale that also fits to common synoptical definitions, such as that of closed isobars. The outcome of this effort was the use of two methods, one which is based on the dynamic field through relative vorticity, and the other on the thermodynamic properties through the geopotential height. In both methods, we calculated the average vorticity and the average geopotential height at the surrounding points with a gradually increasing distance from the minimum (referred to as the low center). In the first method, the scale was defined by the distance of the first point at which the average vorticity changed sign and became negative or alternatively attained a minimum, whichever occurred first. A minimum was first found in only about 14% of the 192 lows. By the second method, the cyclone scale was defined by the distance at which the average geopotential height $\bar{Z}$ stopped increasing, when moving outward from the low center, i.e., $\Delta\bar{Z} = 0$, or alternatively where $\Delta\bar{Z}$ attained a minimum, whichever occurred first. In about 25% of the cases, the minimum was found first. The scale thus defined by the geopotential height variation $\Delta\bar{Z}$ was in general larger than that defined through vanishing (or minimum) vorticity; the average separation between the two derived scales was about 3° (~300 km). In most cases, the two scales were quite close to each other and changed from cyclone to cyclone in similar fashion. The cyclone scale in this study was therefore defined as the average of the two scales obtained by the two methods.

3. Analysis results

3.1. Cyclone distributions and selection of the EM CS cyclones

Fig. 1 presents the number distribution of cyclones according to scale in intervals of 2° (about 200 km). A 3-point running mean was applied in order to take into account the uncertainty of cyclone scale which is estimated to be about 200 km. The results indicate maximum frequencies at the horizontal scales of ~1200 km and at ~3200 km. Secondary maxima are not as significant and may be more dependent on the sample size. The number distribution of cyclones according to the upper air 500 hPa average temperature T_{500} and the near-surface temperature average at 1000 hPa, T_s, are shown in Fig. 2. Two distinct maxima are noticed at cold and warm temperatures. At the 1000 hPa surface, the temperatures are ~14°C and ~19°C (−21°C and −17°C, respectively, at the 500 hPa; notice the slightly different temperature scale). Of interest when studying polar lows are those cyclones which

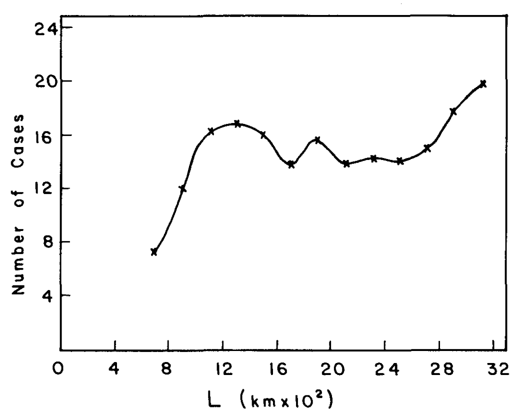

Fig. 1. The number distribution of cyclones according to scale in intervals of 200 km, based on objectively analysed 1000 hPa minima at the ECMWF datasets for 1982–1986. A 3-point smoother was applied, see text.

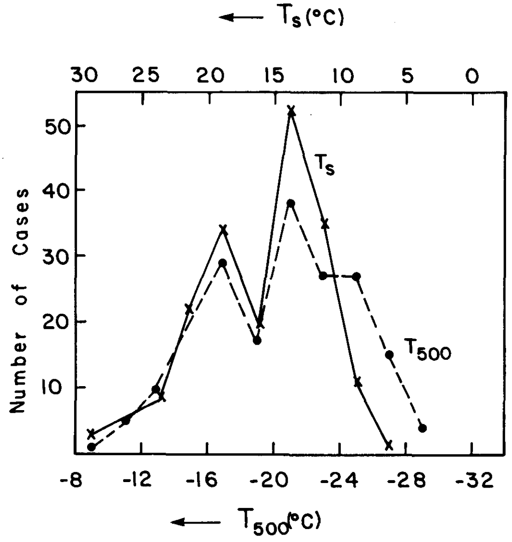

Fig. 2. The number distribution of cyclones according to average temperatures T_{500} (dashed) and T_s (solid) at 500 and 1000 hPa, respectively. Notice the slightly different temperature scale, i.e., interval of 2.5°C for T_s (upper scale) and 2°C for T_{500} (lower scale).

belong both to the smaller scale ($\sim$1100 km) and to the cold-temperature regime. The distribution of the two cyclone populations is shown in Figs. 3 and 4, where each cyclone is indicated by a point according to its scale and its average temperature,

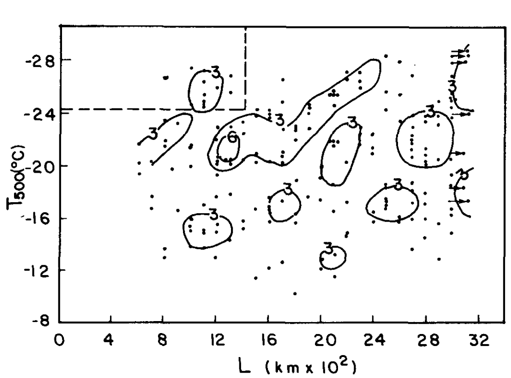

Fig. 3. Cyclone population according to horizontal scale L and 500 hPa average temperature T_{500} (°C). Isolines of cyclone density are drawn at intervals of 3 per unit area. Unit area is defined by a ΔT_{500} interval of 2°C and a horizontal scale of $\Delta L = 200$ km. Threshold values of $T_{500} = -24°$ and $L = 1300$ km are drawn with dashed lines (see text). The arrows to the right represent cyclone scales that are beyond $L \simeq 3000$ km.

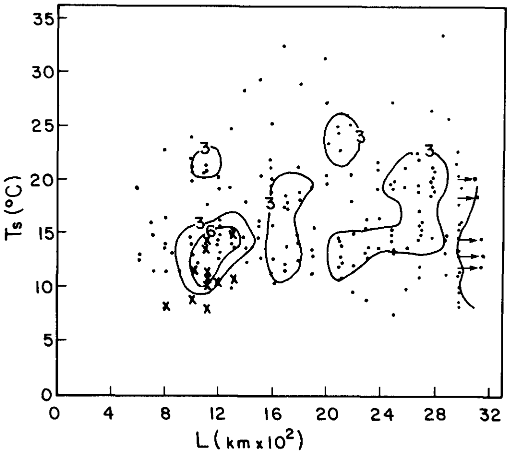

Fig. 4. As in Fig. 3, but with respect to 1000 hPa average temperature T_s. Temperature interval ΔT is 2.5°C. The × 's indicate the EM CS cyclones.

T_{500} or T_s, respectively. Isolines of the cyclone density are also drawn at intervals of 3 per unit area, where the unit area is defined by a ΔT interval of 2°C (2.5°C) at 500 hPa (1000 hPa), and by a scale interval ΔL of 2° $\sim$200 km.

Various cyclone groups are depicted through this method, but the group which seems certain to include cold small-scale cyclones is that at the upper-left in Fig. 3. If we choose the threshold values of -24°C for T_{500} and 1300 km for the horizontal scale L, only 12 colder and smaller-scale cyclones are left. As expected, these EM CS cyclones also belong to the coldest surface temperature group as indicated in Fig. 4 by the × 's.

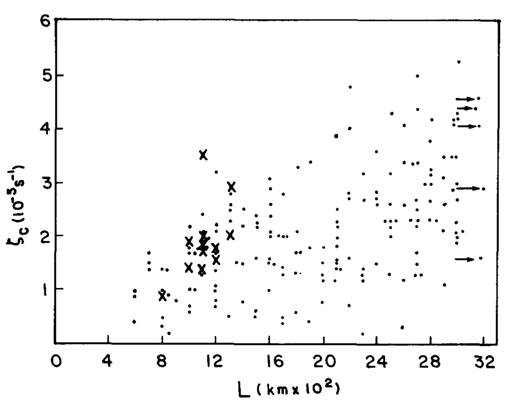

Fig. 5. As in Fig. 4, but with respect to the vorticity ζ_c (10^{-5} s^{-1}) at the low center.

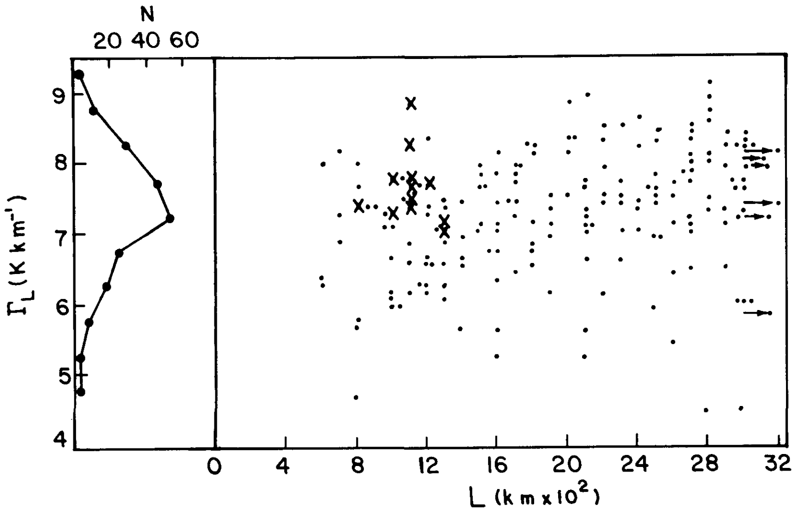

Fig. 6. As in Fig. 4, but with respect to the 1000–850 hPa lapse rate Γ_L. In addition, the number distribution N is plotted on the left at intervals of $\Delta\Gamma = 0.5$ K km^{-1}, with the scale in the upper-left.

3.2. Characteristics of EM CS cyclones

Figs. 1–4 indicate an increased cyclone density in areas corresponding to small scale and cold temperatures (both surface and 500 hPa), which may be therefore considered as the distinct group of CS cyclones. The other groups also seem to be quite unambiguously defined and represent different cyclone types well-known to Mediterranean meteorologists. The warm small-scale cyclones, for instance, are generally the spring depressions or Sharav cyclones (lower-left group in Fig. 3 or upper-left group in Fig. 4), and were reviewed at length by Alpert and Ziv (1989). Since our focus here is on the CS group, the next step is the isolation of the various characteristics of its 12 members.

It is interesting to find that the central vorticity generally increases with scale, see Fig. 5. Above the value of $\zeta_c = 3.5 \cdot 10^{-5}$ s^{-1}, for instance, all cyclones are with an horizontal scale exceeding ~2100 kms. Consequently, the central vorticity at

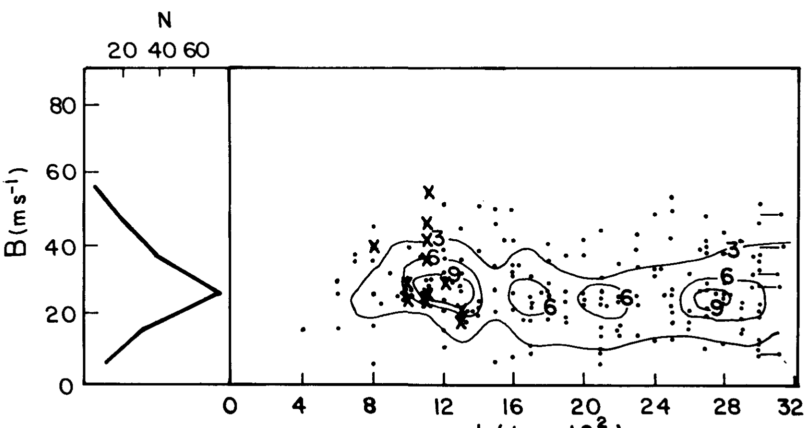

Fig. 7. As in Fig. 4, but with respect to baroclinicity B. The number distribution N is as in Fig. 6 but with an interval of $\Delta B = 10$ ms^{-1}.

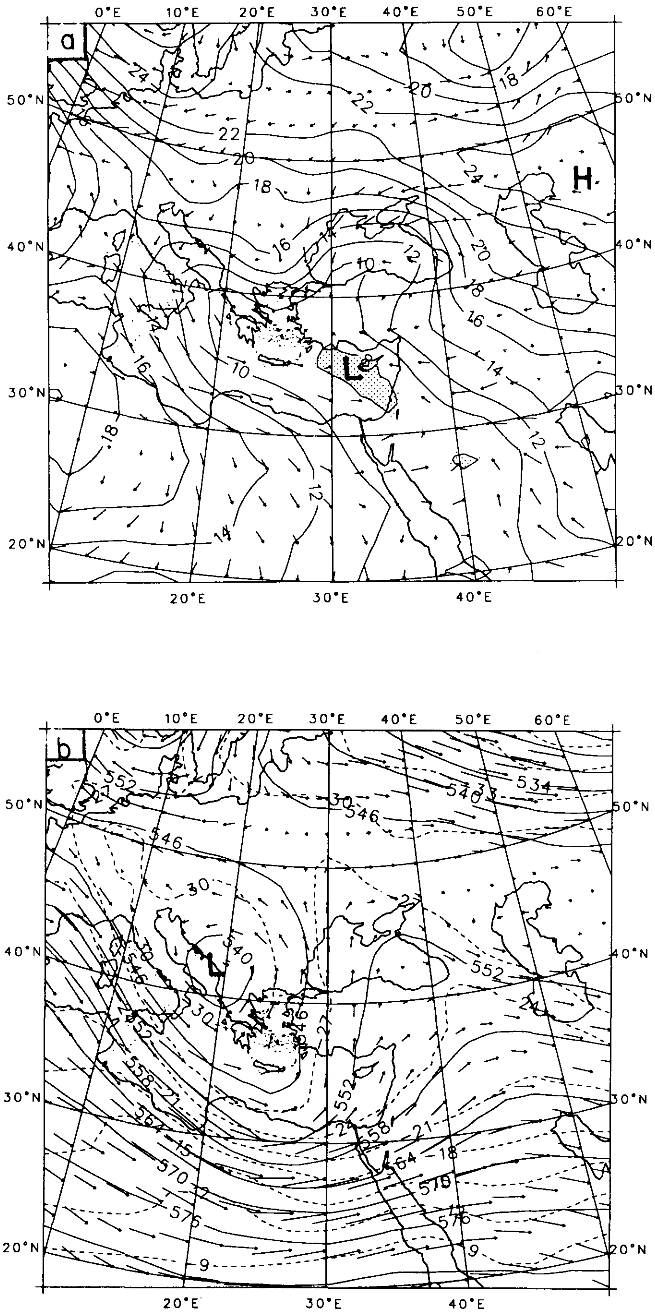

Fig. 8. Analysis 1200 UTC, 13 February 1986. (a) 1000 hPa geopotential height (dam) along with the horizontal wind vector. Values of geopotential height below 80 m ($\sim$1008 hPa on pressure map) are shaded. Wind vector arrows represent 9-h displacement. Contour interval is 2 dam. (b) 500 hPa geopotential height. Wind vector arrows represent 6-h displacement. Dashed lines are isotherms with interval of 3 K. Full lines are geopotential height with 6 dam intervals.

the EM CS cyclones is below $3.5 \cdot 10^{-5}\,s^{-1}$ and generally is around $1.5–2 \cdot 10^{-5}\,s^{-1}$. This finding (as well as all others) is certainly influenced by the relatively coarse ECMWF grid, and mesoscale datasets are required to investigate the central vorticity behaviour of the smaller-scale cyclones below ~500 km. However, the position of CS cyclones is clearly within the higher vorticity levels for their corresponding horizontal scale.

Another important feature in studying cyclones is the level of static instability which was reported to be relatively high in polar lows, (see, for instance, Rasmussen, 1979). Fig. 6 presents the average lapse rates (Γ_L) within the EM CS cyclones along with all other cyclones. As expected, about 50% of all cyclones had an average lapse-rate of 7.5 ± 1 K km^{-1} which is nearly the exact average between the corresponding moist and the dry adiabatic lapse-rates. For a temperature $T_s \approx 11$°C (Fig. 4) and a mid-level pressure of 925 hPa, the saturation lapse rate Γ_s is 4.93 K km^{-1}, see, e.g., Gill (1982, eq. A4.12), and the dry adiabatic lapse rate ~10 K km^{-1}. The CS cyclones are positioned quite close to the average value of Γ_s and Γ_d, i.e., ~7.5 K km^{-1} except in two cases (where $\Gamma_L = 8.6$ and 8.9, Fig. 6) that were extraordinarily dry, and therefore the lapse-rate was closer to that of a dry adiabatic.

Next, the baroclinicity was investigated. A relatively simple indication for this was assumed to be the average vertical wind shear (B) from 850 to 300 hPa. Fig. 7 presents the B-value for the nearly 200 EM lows, including the CS cyclone group, and it shows that this group's baroclinicity is slightly greater than is typical in the total population of EM cyclones. The most frequent value is 25 ms^{-1} and the average for the 12 CS cyclones is 31 ± 10 ms^{-1}.

The importance of the latent heat fluxes from sea surfaces in polar low development was well established in the recent decade since the original suggestion by Rasmussen (1979), who associated the polar lows with the CISK mechanism. A similar analysis to that done earlier (Figs. 3–7) was performed for the average latent heat flux FQ, and it indicated that the EM CS cyclones are typified by relatively average values: 103 ± 30 W m^{-2}. The range of FQ values in 43 other lows was 98 ± 58 W m^{-2}.

High variability was found in H_{70} (the thickness of the layer with relative humidity exceeding 70%), varying from nearly zero in 3 cases to a maximum of 8.9 km on 13 February 1986. The CS cyclone average was 2.8 km, only slightly higher than the total average of 2.6 km with a standard deviation of 2.6 km, see Figs. 8a, b, following a discussion in Section 4.

Another matter of concern is the location of the EM CS cyclones relative to the jet-streams. As expected, in all cases, the jets were found southward of the CS cyclones at an average distance of 7.5° ~800 km. All EM CS cyclones were found in mid or late winter. Only 1 was found in December (28 December 1982), 2 in January, 6 in February and 3 in early March.

4. Conclusions

An objective selection of all eastern Mediterranean cyclones based on the ECMWF data for the 4 winter seasons of 1982–86 was performed. A distinct group of cold small-scale cyclones was identified for which the typical horizontal scale was 1100 km and the temperatures were the coldest, on average less than −24°C at 500 hPa. A few variables have been examined for all cyclones in order to identify special characteristics of the eastern Mediterranean cold small-scale cyclones. The main conclusions are as follows.

(i) They occur mainly in February with their low center at the northern coast of the EM, (Alpert et al., 1990b) 750 km northward of the major jetstream.

(ii) Their central vorticity attains high values relative to cyclones with similar horizontal scale.

(iii) The low tropospheric (1000–850 hPa) static stability is close to the total average of ~7.5 K km^{-1}, a value which seems to result from the exact average between the moist and dry adiabatic lapse-rates.

(iv) They are in general slightly more baroclinic than an average EM cyclone. At the same time, the latent heat fluxes are also larger than average, indicating the importance of local convection.

Note that the analyses of the present study are for situations where the CS cyclone is already in existence. Thus, these results do not necessarily indicate the conditions favourable for the initial development of CS cyclones.

It should be mentioned that an inspection of the operational synoptic maps for each member of the EM CS cyclones indicated in 10 out of the 12 cases significant convection associated with showers, thunderstorms and sometimes heavy rain. For example, the 13 February 1986 case with $L = 13$, $\zeta_c = 2.0$, was associated with ~ 14 mm in Jerusalem, following the next day with 69 mm, thus amounting to about 20% of the annual normals. Fig. 8 shows the corresponding 1000 and 500 hPa maps for this case with shading below 80 m, equivalent to about 1008 hPa in a surface chart.

According to some investigators, the typical horizontal scale of polar lows is less than 500 km, scales not resolvable in the present study. It is suggested, however, that the aforementioned features that have been found in the cold meso-α (~ 1000 km) cyclones may reflect those of the even smaller scale (~ 200 km) cyclones, even though these features may be less profound in the meso-α. If this is true, then some of the features associated with the EM CS cyclones may also apply to polar low-like phenomena in the Mediterranean, discussed in Section 1. This could be investigated in future studies with the aid of higher-resolution datasets.

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