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Synoptic and dynamic characteristics of the depressions that affected the area of Cyprus during the winter of 2007–2008

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Abstract. The hydrological year 2007–2008 is the second drier in Cyprus since records are kept, for more than one hundred years. Since most of the rainfall is associated with depressions that affect the area during the cold months of the year, a study was carried out to investigate the characteristics of these synoptic-scale systems. The study comprises a statistical analysis of the synoptic and dynamic characteristics of the depressions that affected the area of Cyprus during the winter of 2007–2008.

1 Introduction

The area of Cyprus is affected by baroclinic depressions mainly during the cold period (El-Fandy, 1946; Kallos and Metaxas, 1980). The annual average accumulated precipitation over the area of Cyprus is 503 mm, resulting primarily from baroclinic depressions. Most of the cold period depressions approach the area from the west (Michaelides et al., 2004; Nicolaides, 2005), while some of them either approach from other directions, or develop over the area. The cold period depressions account for the largest share of precipitation over the area (Nicolaides, 2005).

The hydrological year 2007–2008 is quite exceptional, since it is the second drier recorded in the past one hundred years (second to 1972–1973). Bearing in mind the above, an investigation was carried out in order to reveal some characteristics of the 2007–2008 winter-time depressions that affected Cyprus.

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The present study covers the cold period of 2007–2008, namely the months November–December 2007 and January–February 2008. During the study period, only a few depressions affected the area, resulting in only 204mm of accumulated precipitation; this corresponds to a mere 41% of the annual normal (or to 59.4% of the corresponding months' normal, see Fig. 1). January and February which normally account for more than 180 mm of accumulated precipitation, resulted in less than 80 mm.

All of the depressions that affected the area of Cyprus during the study period were subjectively identified and classified, according to their origin and the direction of their entrance into the area. Their synoptic and dynamic characteristics were studied and compared with results from long term mean, in order to identify the reasons for the very poor precipitation accumulations over the area of Cyprus.

In Sect. 2 an outline of the implications of low rainfall is given. The methodology adopted is presented in Sect. 3, while Sect. 4 presents the results. Concluding remarks are given in Sect. 5.

2 Implications of prolonged low rainfall

The low levels of accumulated precipitation had a severe impact, not only on the agricultural sector of the economy of the country, but also on the water management for domestic-household needs. Indeed, part of the precipitation that reaches the ground is stored in reservoirs created with the construction of dams in suitable catchment areas. This stored water, water from bore holes, springs, wells and water from desalination plants, is distributed to cover several domains, such as household, tourist industry, agriculture and other industrial activities with lower water requirements. The management system of water distribution is always a difficult task for the authorities and was even more difficult at present, since several of the previous years were also drier

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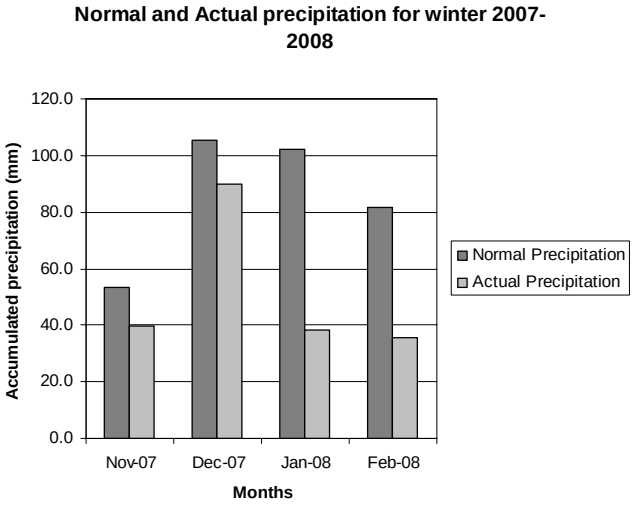

Fig. 1. Monthly total precipitation for November 2007 to February 2008, compared to the respective monthly normal values.

than normal. Under such prolonged low precipitation conditions, the protection of forests and wild life also poses a difficult task. Indeed, a significant number of forest fires were reported not only during the cold period, but also in the subsequent drier months.

As a result of this prolonged period of low precipitation, water for household usage was distributed in a non-continuous manner, while a system of partial and temporal distribution was in use. Water was transported by sea tankers from Greece to Cyprus at a considerably high cost.

3 Methodology

All of the depressions that affected the area of Cyprus, during the cold period of 2007–2008, were identified and clustered according to the direction of their entrance (i.e. North, East, South, West, or developed over the area of Cyprus). The method used for identification and clustering was subjective and was based on surface analyses charts corresponding to the main synoptic hours and upper air charts corresponding to 12:00 and 00:00 UTC for 850, 700 and 500 hPa. For the purpose of the study, a depression was considered to be a synoptic-scale feature with cyclonic curvature and with the value of the surface pressure of its innermost closed isobar less than or equal to 1016 hPa (this threshold was selected by the authors in previous studies and it is also selected herein, as a reference).

A simple statistical analysis was initially performed, regarding the surface pressure of their innermost closed isobar. The results were compared with results from previous studies in order to identify possible synoptic reasons explaining the poor precipitation of the cold months set under study. A dynamic analysis was also performed for each cluster regarding the spatial and temporal distribution of the mean geopotential height, temperature, static stability, relative vorticity and divergence of the components of the horizontal wind vector, over various isobaric surfaces for various days; the day the depression had its lowest innermost closed isobar surface pressure (which was set as D0), the day after (set as D + 1) and the previous day (set as D − 1). The results were also compared with results from previous studies covering the cold month's depressions of the period 1988 to 2003 in order to identify any dynamic reasons for the poor precipitation of the cold period in question.

The numerical forms of the equations, in spherical coordinates, used for the mathematical calculations are (see also Nicolaides et al., 2004, 2005):

$$\delta = \frac{1}{r\cos\phi}\frac{\Delta u}{\Delta\lambda} + \frac{1}{r}\frac{\Delta v}{\Delta\phi} - v\frac{\tan\phi}{r} \quad (1)$$

$$\zeta = \frac{1}{r\cos\phi}\frac{\Delta v}{\Delta\lambda} - \frac{1}{r}\frac{\Delta u}{\Delta\phi} + u\frac{\tan\phi}{r} \quad (2)$$

$$\sigma = \frac{gT}{c_p} - \frac{pg}{R}\frac{\Delta T}{\Delta p} \quad (3)$$

where δ (Eq. 1) is the divergence of the wind, ζ (Eq. 2), the relative vorticity and σ (Eq. 3), a static stability index. Also, r is the radius of the Earth, λ longitude, ϕ the latitude, g the vertical component of the acceleration of gravity, c_p the specific heat of dry air under constant pressure, p the atmospheric pressure, R the universal gas constant and u and v the horizontal components of the wind vector, respectively. The above expression of the static stability index σ, was used in other studies (e.g., Michaelides, 1987, 1992). In this paper, only the results for selected levels are presented, for brevity. The results presented below in the form of spatial distributions comprise averages of the respective parameter, considering all cases in the respective cluster.

The NCEP/NCAR 00:00 UTC global reanalysis data with grid resolution $2.5° \times 2.5°$ were used in order to perform the necessary mathematical calculations for the dynamical analysis. The calculations covered the area bounded by the meridians 20° W and 50° E and the parallel circles 20° N and 65° N. The surface charts and upper air analyses corresponding to 850, 700 and 500 hPa, as well as the rainfall, retrieved from the archives of the Cyprus Meteorological Service, were also used.

4 Results

4.1 Statistical analysis

Previous studies showed that, during the cold months, the area of Cyprus is affected by almost one depression per week (Nicolaides, 2005). Thus, for the cold period of 2007–2008 (i.e., the months November 2007 to February 2008), 16 to 17 depressions would have been expected and for those, almost half would have been expected from the west direction

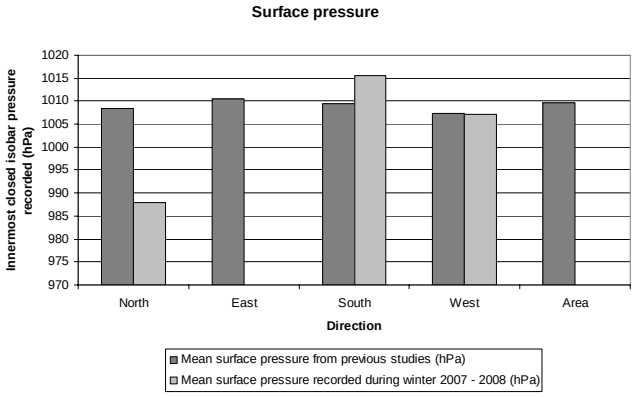

Fig. 2. Comparison between the mean sea level pressure of the clusters in the study period against long term mean.

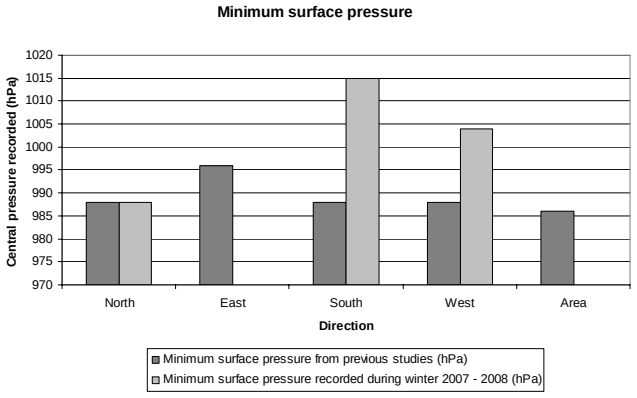

Fig. 3. Comparison between the mean minimum sea level pressure of the clusters in the study period against previous studies.

(Nicolaides, 2005). The depressions that originated from the west were found to be the most favorable ones for precipitation, in the long term mean. From the study of the surface and upper air charts which were retrieved from the archives of the Cyprus Meteorological Service, it was found that the area of Cyprus had "collected" only eight depressions, thus almost 50% of what would have to be expected. The depressions identified were subsequently clustered, according to the direction from which they have entered the area: five depressions from the "West" direction, two from the "South" direction and one from the "North" direction. In Fig. 2, the long term mean of the surface pressure for each cluster is compared to that of the respective cluster in the study period. It was found that the sea level pressure of the innermost closed isobar of the depression classified as "North" was much lower compared to that of the respective long term mean (Fig. 2). It was also noted that the central pressure of this depression from the "North" was found to be 988 hPa, equal to the minimum surface pressure recorded from previous studies (Fig. 3). The comparison reveals almost the same value for the mean sea level pressure for cluster "West" and a larger value for cluster "South", while the minimum sea level pressure recorded is greater than the one recorded from previous studies (Nicolaides, 2005).

In contrast to results from previous studies, during the study period, there is a complete absence of depressions from the East and depressions forming over the area.

4.2 Dynamic analysis

In order to identify reasons for the low accumulated precipitation in the study period, an analysis concerning some of the dynamic characteristics of the depression clusters was performed. The analysis covered the isobaric layers of 850, 700, 500 and 300 hPa. Calculations were performed for each cluster, for each day, $D-1$, D0 and $D+1$. The calculated and examined dynamic parameters were the divergence (Eq. 1) of the horizontal wind field, relative vorticity (Eq. 2), a static stability index (Eq. 3) and omega (for detailed documentation see also Michaelides, 1987, 1992). For the needs of the present study, a composite analysis of the fields of temperature and geopotential height was performed for the respective day and cluster. Not all of the charts and combinations between parameters and isobaric levels will be presented, due to space limitations; a reference to some of the calculations of not-presented fields will be made.

Cluster "Depressions from the North"

Only one depression affected the area of Cyprus, during the study period, originating from the North. The spatial distribution of its 500 hPa height, at time D0, demonstrates that this depression was very deep, with a geopotential height of 5400 gpm over the area (Fig. 4). The axis of the relatively sharp trough was extending from northeast of Black Sea towards the North African coasts. At the same time, Europe and the west region of the Mediterranean were covered by an area of high pressure. The strong southwest to west medium tropospheric air flow over the east Mediterranean, as well as the northerly airflow over the Aegean, were very well pronounced. Noteworthy also was the cyclonic curvature over the area of interest inducing cyclonic vorticity of more than $14 \times 10^{-5}\,s^{-1}$ over the area of west Asia Minor. The area of Cyprus is marked by a spot value of relative vorticity of $7 \times 10^{-5}\,s^{-1}$. As found in previous studies (Nicolaides, 2005), depressions that belong to the cluster "North" had a mean geopotential height over the 500 hPa isobaric surface of only 5610 gpm, thus 210 gpm shallower than the depression in question. The mean relative vorticity of cluster "North" depressions, as found from previous studies, was $5 \times 10^{-5}\,s^{-1}$, over the area of north Aegean and a lower value over Cyprus.

From the study of the field of lower tropospheric divergence in Fig. 5, a strong field of lower tropospheric convergence (negative divergence values) was recognized over the area of Asia Minor and east Mediterranean. The field

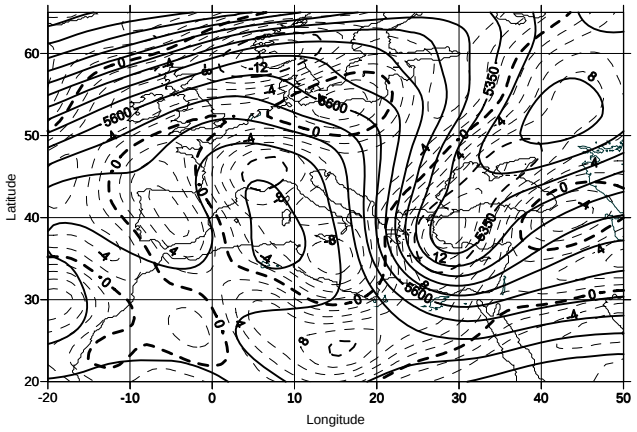

Fig. 4. Geopotential height (solid lines, gpm) over the 500 hPa isobaric surface and relative vorticity (dashed lines, $\times 10^{-5}\,s^{-1}$) over the 300 hPa isobaric surface for the cluster "North", at time D0.

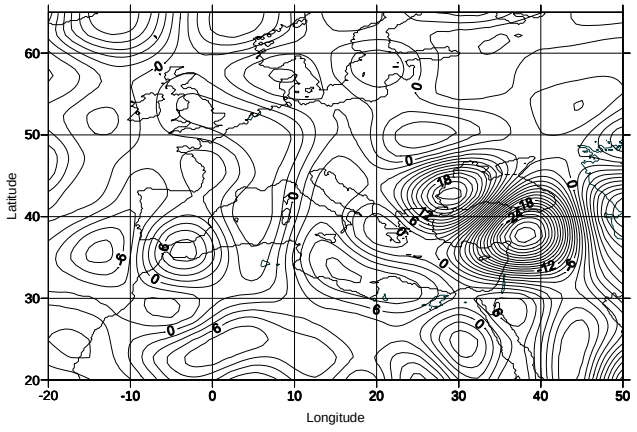

Fig. 5. The divergence of the horizontal wind vector over the 850 hPa isobaric surface ($\times 10^{-6}\,s^{-1}$) for the cluster "North", at time D0.

of divergence over the upper tropospheric levels of 300 hPa (calculated, but not presented) is characterized by large divergence values. The combination of the fields of divergence over the two tropospheric layers resulted in enhanced updrafts and clouds formation over the entire tropospheric column of the area of interest.

This depression was very well organized and affected the area of the east Mediterranean during late January 2008. It resulted in 26.5 mm of accumulated precipitation (averaged over Cyprus) which, when compared with the normal of the month, corresponds to 25%. Its main characteristics were associated with its air mass, which was cold and relatively dry due to its continental origin. Lower than normal temperatures were also recorded over the island of Cyprus; Troodos range and areas with relatively low altitude were covered by snow.

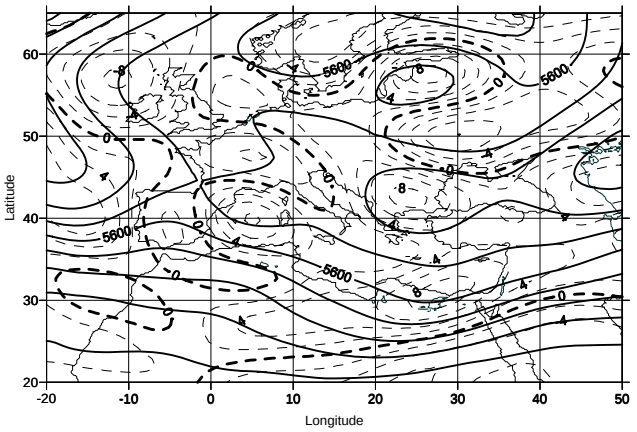

Fig. 6. Geopotential height (solid lines, gpm) over the 500 hPa isobaric surface and relative vorticity (dashed lines, $\times 10^{-5}\,s^{-1}$) over the 300 hPa isobaric surface for the cluster "South", at time D0.

Cluster "Depressions from the South"

Only two depressions originating from the South affected the area of Cyprus during the study period. The first depression affected the area during early January and the second during middle February. These two depressions were associated with dust events, since their origin was the area of North Africa and the Sahara desert. The associated air mass was hot and dry over the lower troposphere. While passing over the sea the lower tropospheric layer was modified with moisture having picked-up from the Mediterranean; they depressions followed a northward path thus the associated lower tropospheric air was placed over a relatively colder surface, leading to reduced lower level instability. Such types of depressions can yield stratiform rain-type precipitation as well as convective precipitation from medium level instability. At the 500 hPa isobaric level, the mean geopotential height over the area of Cyprus in the study period was 5550 gpm (Fig. 6); previous studies showed that the mean geopotential height for the depressions in cluster "South" was 5510 gpm, thus in the current study cases, the corresponding value was 40 gpm lower. A weak trough over the Balkans associated with cyclonic vorticity was noted (see Fig. 6). Another area associated with cyclonic vorticity was found over north Egypt, with values of $8 \times 10^{-5}\,s^{-1}$. The area of Cyprus had a spot value of relative vorticity $6 \times 10^{-5}\,s^{-1}$, while in previous studies a value of $4 \times 10^{-5}\,s^{-1}$ was found.

The depressions originating from the south direction could result, according to previous studies (Nicolaides, 2005) in higher precipitation scores but the ones of the present study had such a path and lower tropospheric characteristics that were rather inhibitory to high accumulated precipitation.

From the study of the field of lower tropospheric divergence of the horizontal wind vector (see Fig. 7) an area with negative values of divergence (i.e., weak lower tropospheric convergence) was present just to the west of Cyprus.

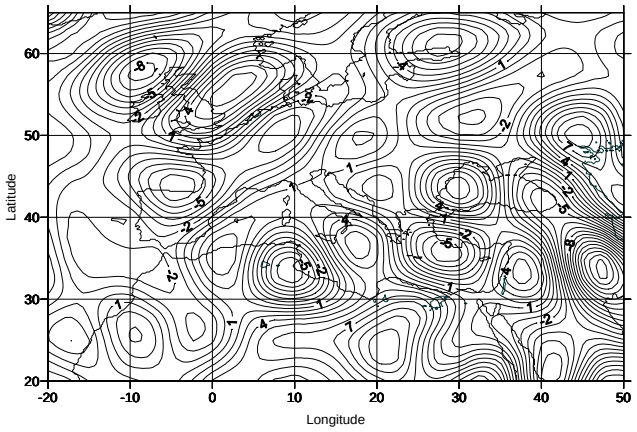

Fig. 7. The divergence of the horizontal wind vector over the 850 hPa isobaric surface ($\times 10^{-6}\,s^{-1}$) for the cluster "South", at time D0.

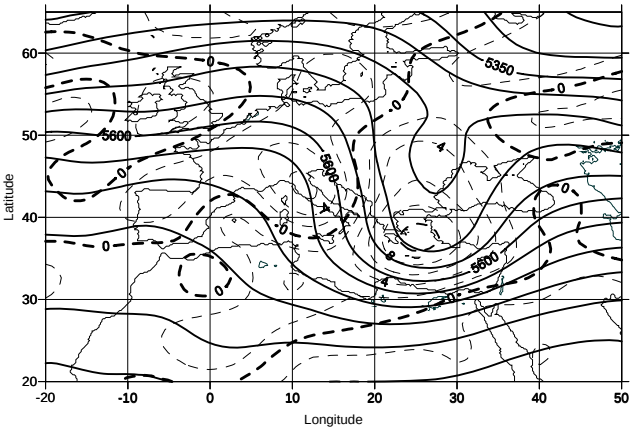

Fig. 8. Geopotential height (solid lines, gpm) over the 500 hPa isobaric surface and Relative Vorticity (dashed lines, $\times 10^{-5}\,s^{-1}$) over the 300 hPa isobaric surface for the cluster "West", at time D0.

The field of divergence over the upper tropospheric level of 300 hPa (calculated, but not presented) was characterized by weak divergence values. The combination of the weak fields of divergence over the two tropospheric layers resulted in weak updrafts and cloud formation over the area.

Cluster "Depressions from the West"

The depressions originating from the west direction were the main contributors to precipitation accumulations over the area of Cyprus. Only five depressions affected the area from the west direction during the study period; two of them during November, another two during December and the last one during February. As seen from Fig. 1, their contribution to the accumulated precipitation during November and December was significant. The mean 500 hPa geopotential height was 5580 gpm over the area of Cyprus, roughly the same found in previous studies. From the reconstruction of the field of geopotential height (Fig. 8), a distinct wave can be recognized, with a trough extending from just west of Black sea towards Crete and further southwards and a ridge covering the central and western Europe. The extension of the trough was found to be sharper compared to previous studies. The relative vorticity (also in Fig. 8), induced primarily by the trough's curvature, obtained a maximum of $10 \times 10^{-5}\,s^{-}1$ over the Aegean. Compared to previous studies, the mean relative vorticity value of the cluster "West" was only $6 \times 10^{-5}\,s^{-}1$ and that south of the area of Crete. Over the area of Cyprus a value of $4 \times 10^{-5}\,s^{-1}$ was found. The depressions of cluster "West" during the cold months travel over the relatively warm Mediterranean Sea towards east Mediterranean. Their passage over the Mediterranean modifies their lower tropospheric layers by moisture absorption. Their air mass becomes gradually unstable yielding thunderstorms and showers. These depressions account for high levels of precipitation over the area of Cyprus.

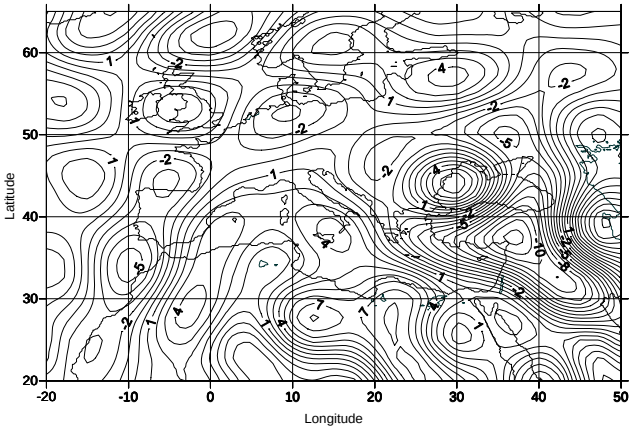

Fig. 9. The divergence of the horizontal wind vector over the 850 hPa isobaric surface ($\times 10^{-6}\,s^{-1}$) for the cluster "West", at time D0.

From the study of the field of lower tropospheric divergence of the horizontal wind vector (Fig. 9), an area with negative values was noted over the area of the east Mediterranean (thus denoting lower tropospheric convergence). At the upper tropospheric level of 300 hPa divergence obtains positive values over the same area (calculated, but not presented). This combination of the fields of divergence over the lower and upper tropospheric layers (convergence and divergence respectively) results in moderate updrafts and cloud formation.

5 Concluding remarks

The cold months of November–December 2007 and January–February 2008 were examined in order to identify any synoptic and dynamic causes for the poor accumulated precipitation over the area of Cyprus. From the statistical

analysis performed, it was found that the total number of depressions, which have affected the area, was much less than those expected on the basis of previous studies. A depression which affected the area from the north direction was very deep, but due to the dryness of the associated air mass, its contribution to the accumulated precipitation was quite poor. The five depressions from the west direction contributed the majority of accumulated precipitation amounts but were not sufficient to close the gap of precipitation deficit.

Their dynamic characteristics were those expected hence the only finding of the poor accumulated precipitation was the number of depressions that affected the area. Further study focused on the general atmospheric circulation of the time period in question is in progress, while an atmospheric block is suspected generally over Europe, resulting in anticyclonic conditions over the area of the east Mediterranean.

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