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A CLIMATIC INVESTIGATION OF PRECIPITATION AMOUNT ASSOCIATED WITH 500-HPA CYCLONES WHICH ARE AFFECTING THE GREEK TERRITORY DURING WARM PERIOD OF THE YEAR

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Abstract: An objective analysis of 500-hPa cyclones (500-hPa lows) is performed during the warm period (15 Apr-15 Oct) of the year for central and east Mediterranean regions. A 40-year (1958-1997) data basis of geopotential height values with a detailed (2.5°X2.5°) spatial and temporal (00, 06, 12, 18 UTC) resolution is used in the study. Lows are determined as local minima in each 3X3 matrix of geopotential height values for every grid point in the area of study. A gradient criterion between the central point and the surroundings is additionally applied to exclude weak lows, which probably originate from the assimilation procedure. A sub-area which consists of 36 grid points and includes the Greek peninsula is selected for the investigation of relationship between cyclone occurrence and precipitation amount. Cyclone occurrence is classified in nine groups consisting of four (4) grid points each. During the domination of these cyclones, daily precipitation amounts where determined from precipitation data collected at a 20-station network, which was operational during the same time period. In cases of multiple cyclone occurrences per day, the location of the deepest cyclone was selected. The spatial distribution of average precipitation amount in each of the nine cyclone groups is plotted and discussed. The comparison of these nine distributions revealed three major factors affecting the location of frequency maxima and minima. The first is low-level instability, the second is orography and the third is positive vorticity advection associated with 500-hPa cyclones.

Keywords : 500-hPa cyclones, Greece, warm period of year, precipitation, orography, positive vorticity advection.

1. Introduction

Warm season precipitation in the Mediterranean is very important for the yearly water balance. Precipitation is also closely related to natural hazards such as flash flood and soil erosion. These natural hazards are usually producing severe damages in both natural and anthropogenic environment. They are also very destractive to both plants and agricultural yield, because during the warm period of the year, plants are in active development stage. Destructive effects include plant inclination (e.g. cereals in mature stage) bursting of fruits (especially cherries) and fungi infections when precipitation is combined with the absence of direct solar radiation. Moreover, the flooding of cultivated areas in early stages usually causes the destruction of plants through asphyxiation of seeds.

There are several synoptic causes for precipitation events during the warm period of the year (15 April to 15 October). At the beginning and the end of this period, a great variety of middle latitude depressions affects the area with identifiable surface and upper air features such as fronts and low pressure centres. Among the synoptic causes, the African (Saharan) depressions at the north –west of this region, play for example an important role on precipitation in western or southern Greece especially during middle/late spring and middle autumn (Prezerakos, 1985). But by the time summer sets in, a lack of identifiable surface features is evident and only upper air disturbances can be detected. The upper air low or cyclone remains among the most easily identifiable features. The situation which is presented in figure 1 (a 500-hPa handmade analysis at 00 UTC in the 1st of May 1997), is a synoptic example of a severe precipitation event. A series of troughs around the low centre is indicated by their axes as dotted lines. The closed low at geopotential height field which has its centre over the Balkans (Fig. 1) is also combined with a pocket of cold air (-30 °C) at the same level. The cold air mass which usually extends to lower and upper levels is the reason for naming these synoptic features “cold pools” (Papagiannakis, 1967) in the early stages of synoptic meteorology. Weather conditions under the domination of such synoptic situations have been studied only for certain places in Greece (Maheras, 1982). For example in Thessaloniki, Maheras notices the slow movement of cold pools toward the east and the production of a daily precipitation amount of an average 5.3 mm. The long lasting cloud cover, the high relative humidity (70% on the average) and the small daily variation of the temperature is also noticed.

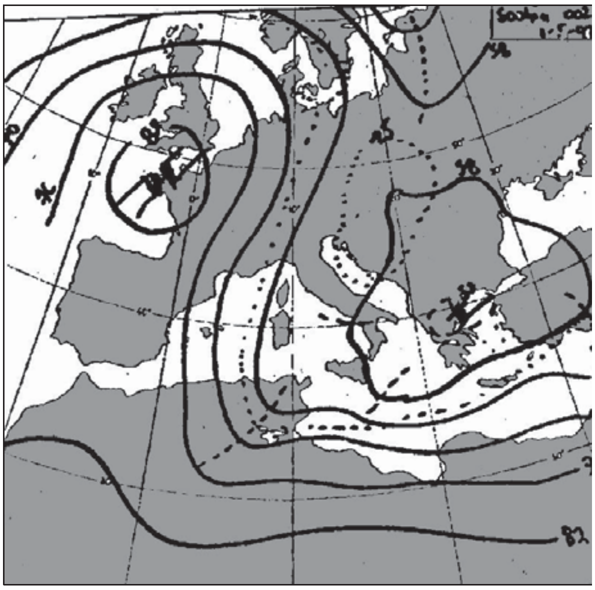

Fig. 1. A 500-hPa handmade analysis which is associated with a severe flood in central Greece on 1st May 1997 (Greek Meteorological Service).

Concerning precipitation distribution in Greece and its connection to atmospheric circulation, several studies have contributed results. The majority of them however, mainly refer to winter precipitation. A study by Laliotis (1977) uses subjective synoptic analysis every 12 h and precipitation measurements at several stations but the data base covers only a decade. Among the objective studies for the area, useful results are found in the studies by Xoplaki et al., (1999) and Bartzokas et al., (2003). More recently (2008), a study by Houssos et al., deals with the association between extreme precipitation and circulation patterns by using analysis on a 33-year data basis (1970-2002). The present study is based on an objective analysis (Spanos, 2004) which employs a 40-year data base for the geopotential height and precipitation and focuses on warm period precipitation.

2. Materials and Methods

The 40-year (1958-1997) NCEP/NCAR reanalysis gridded data of geopotential height with a 2.5ºx 2.5º spatial and 6-h temporal resolution (00, 06, 12, 18 UTC) are employed (Kalnay et al., 1996). The investigation covers the warm period of the year (15 April to 15 October). Lows or Cyclones were determined as local minima in each 3X3 matrix of geopotential height values within the area of investigation. A gradient criterion between the central point and the surroundings is additionally applied to exclude weak lows, which probably originate from the assimilation procedure (Trigo et al., 1999). The gradient criterion in the study was produced through an experimentation procedure which is thoroughly described in Spanos et al. (2003) and in Spanos (2004). For example a gradient of 1 gpm per grid-point distance (GPD) overestimates the number of lows by 10% while a gradient of 3 gpm per GPD only by 6%. Overestimation was based on comparison with official subjective analyses. The investigated area (Fig. 2) covers parts of central and east Mediterranean region (30º north to 50º north latitude and 5º east to 35º east longitude). A sub-area which consists of 36 grid points and includes the Greek peninsula is selected for the investigation of the relationship between cyclone occurrence and precipitation amounts. Investigation is based on the detection of daily precipitation events from a 20-station network in Greece which was operational during the same time period (1958-1997). Drizzle (precipitation

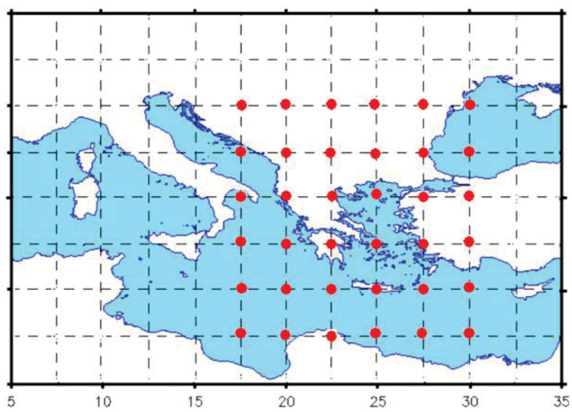

Fig. 2. Map of central and east Mediterranean region where grid lines and points are indicated. Dotted grid points represent the area for the precipitation investigation.

height=0 mm) was excluded from the sample. The occurrence of 500-hPa cyclones in the sub-area was examined only when at least one station indicated measurable precipitation. Only the events with cyclone occurrence in the sub-area were considered. In order to assign only one cyclone occurrence to each daily precipitation event, the deepest cyclone of the day was finally considered.

Cyclone occurrence in the sub-area is divided into nine (9) groups. Each group consists of 4 grid points and is characterized by its orientation in the investigated area. The characterization involves two letters (e.g. SW represents the southwest group) and is presented in figure 3. The number below the name of the group shows the number of cyclone occurrences.

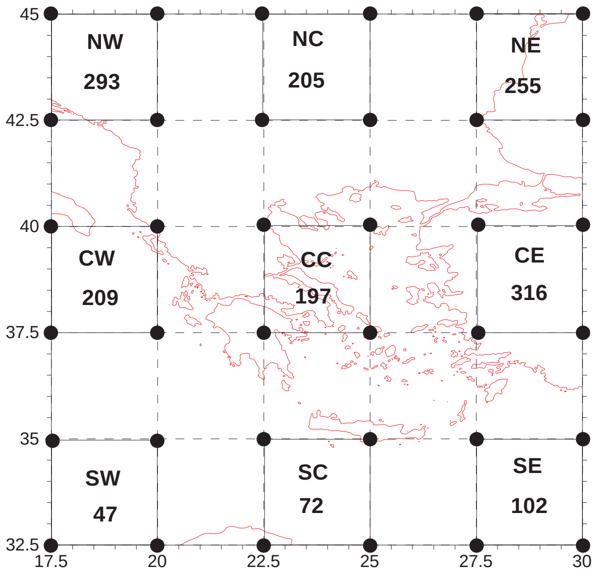

Fig. 3. Characterization of grid points according to their orientation in the investigation area. Below the group names, the numbers of cyclone occurrences are indicated.

The precipitation measuring network is shown in figure 4. It consists of 20 stations which are almost uniformly distributed over the territory. Daily precipitation amounts were averaged for all stations in each of the nine samples. For each sample a geographical distribution of average precipitation values was produced. The geographical distributions of the average daily precipitation, are presented in figures 5 to 7. Isopleths are drawn by using the Krigging method (Journel and Huijbregts, 1978)

3. Results and Discussion

Figure 5 shows the distribution of average precipitation under the domination of 500-hPa cyclones

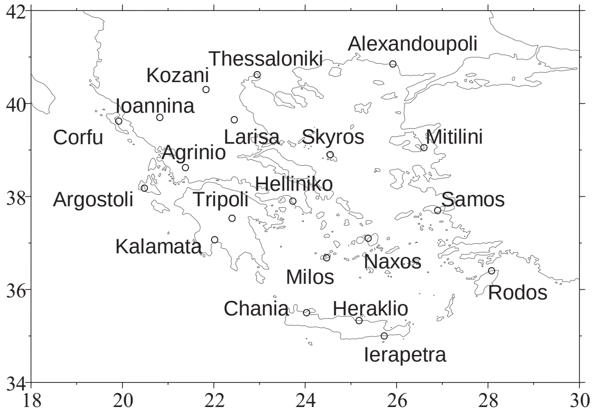

Fig. 4. Location of precipitation measuring stations in Greek territory.

belonging to the central groups (CC, CE and CW). In the CC group a local maximum is observed over central Aegean Sea and Crete Island. In this group the location of maximum values coincide with the location of positive vorticity advection which usually accompanies the cyclones (Prezerakos et al.,1996; Spanos, 2004). In the CE group, maximum values are observed to the southeast as expected. However, there is a second maximum to the northwest which is due to a northwest flow of air masses behind the cyclones. While northwest flow is indicative of ridge building behind the low, there are usually embeded short waves which produce precipitation in certain places. In the CW group, maximum values are observed over the southwest parts and especially over places lying between cyclone centres and the crest of Pindos mountain chain. This mountain chain follows the peninsula from northern Balkans towards the south over the Greek mainland and ends up as Cretan mountains. The two local minima which are located to the east of the maxima indicate the existence of a Lee effect to the east of cyclone centres and the mountain chain. Ascending airflow still produces a second maximum over the Turkish coast.

In figure 6, the average precipitation distributions correspond to cyclones of the northern groups (NC, NE and NW). The average precipitation over Thessaloniki (Fig. 4), which ranges from approximately 5 mm for the first two groups to 6.8 mm for the third group is in very good agreement with the value of 5.5 mm calculated by Maheras (1982) in these synoptic situations. In all northern groups, the dominant factors in the determination of local maxima are primarily the positive vorticity advection and secondarily the location of orography relative to the general flow. Local maxima are observed over the Turkish coast which is to the south or southeast of cyclone centres. A detailed investigation (Spanos, 2004) showed that for the cyclones of these groups the positive vorticity advection usually lies to the southeast of the centres.

Figure 7 shows the distribution of average precipitation under the domination of cyclones belonging to the southern groups (SC, SE and SW). Cyclones in these groups are usually early autumn cyclones which form when cold air enters the Mediterranean basin. Warm basin waters transform cold air masses to relatively warm and unstable masses.

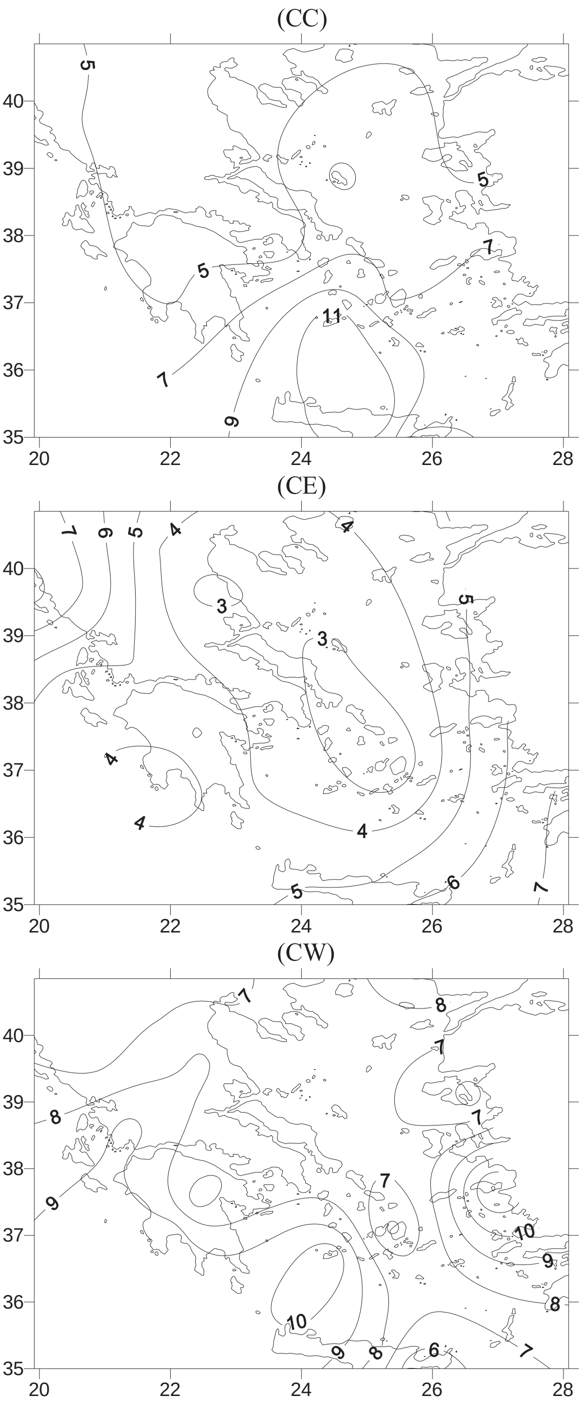

Fig. 5. Spatial distributions of average precipitation (mm) in Greek territory under the domination of cyclones of the central groups, such as central central (CC), central east (CE) and central west (CW) group.

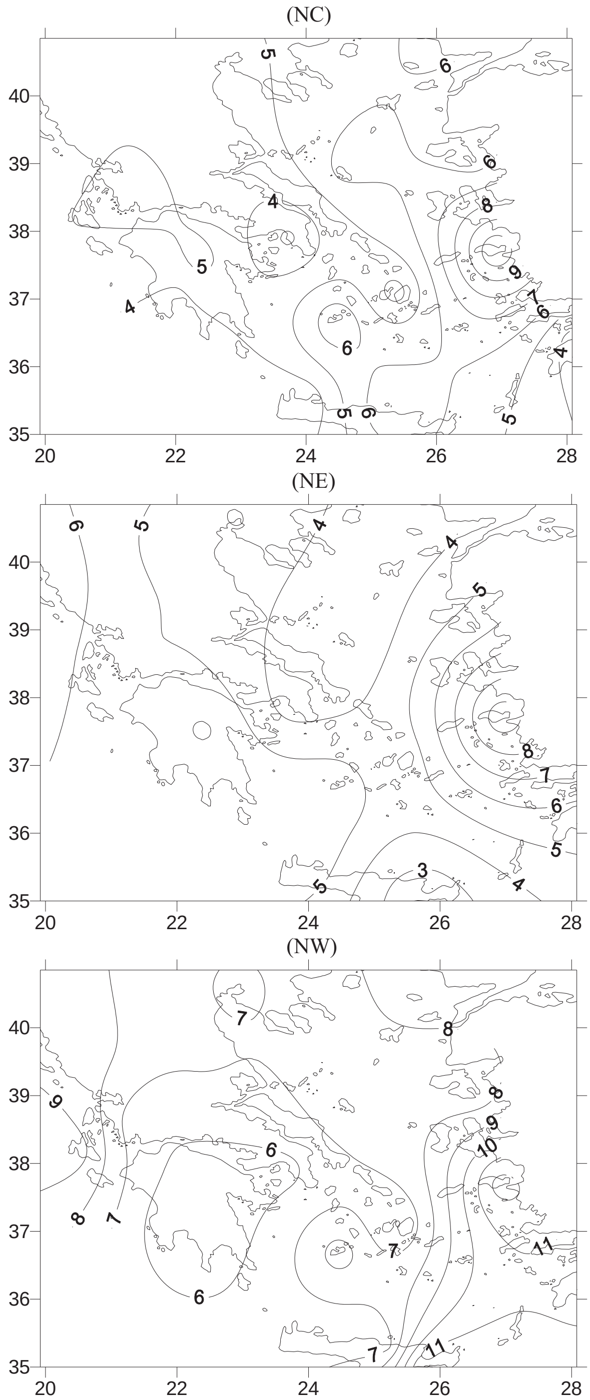

Fig. 6. Spatial distributions of average precipitation (mm) in Greek territory under the domination of cyclones of the northern groups, such as north central (NC), north east (NE) and north west (NW) group.

The cyclones formed by this process are typical middle latitude depressions with frontal surfaces. In these groups, the stage of development of the depressions plays a more significant role than the location of upper air cyclones and modifies precipitation regimes. Warm water process and the resulting instability seem to be the dominant factor in the determination of local maximum in figure 6(SC). A further investigation (Spanos et al., 2003; Spanos, 2004) showed that many of the cyclones in this group are related to occluded depressions which originate in the southwest of Crete (Brody and Nelson, 1980; Prezerakos, 1997). In the SW cyclone group two local maxima (13 mm) are observed. The local maximum of central Crete can be attributed to the easterly flow which is associated with surface lows. The surface lows are usually found to the east of the 500-hPa cyclones, over south Ionian or Aegean Sea, as in the case of 23 October 1994 (Prezerakos et al., 1996). At the southern parts of the surface low northerly flow is produced over Crete, while at the northern parts of the low easterly flow is produced. The combination of these low level flow regimes with the orientation of mountain chain justifies the location of the two maxima over Crete Island and central parts of Greek peninsula. The situation is similar to the described by cluster two in the study of Houssos et al. (2008). In the SE cyclone group the three local maxima are observed over the mountains of the peninsula. As the cyclones of this group have moved toward the east, ridges are built behind them. Under these circumstances, the main factor in the precipitation production is instability over the continental areas. Clearing of the skies permits solar radiation to heat the continent and therefore to produce vertical instability. Local thunderstorms which are developing in the afternoon are responsible for the precipitation maxima.

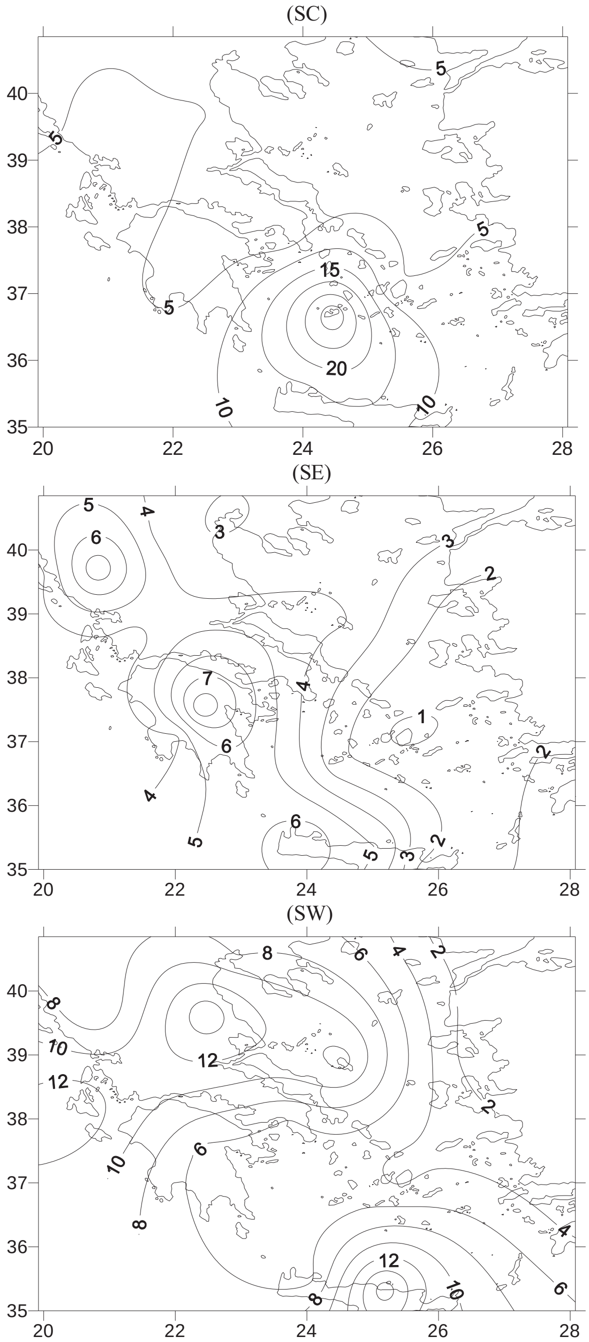

Fig. 7. Spatial distributions of average precipitation (mm) in Greek territory under the domination of cyclones of the southern groups such as, south central (SC), south east (SE) and south west (SW) group.

4. Conclusions

When a 500 hPa cyclone dominates in the vicinity of Greece three main factors determine the location of precipitation. These factors act together but can be identified as primary factors for the various groups of cyclones. The first is the vertical instability produced by the combination of cold air aloft with warm air at the lower levels. Warm air at lower levels results from surface heating of air masses. Surface heating is developed over the continents by solar radiation as in the case of SE or NW groups. It may also be developed over warm waters resulting from heat storage as in the SC cyclone group. The second factor is the combination of orography and the orientation of Pindos mountain chain relative to the flow patterns. This factor plays an important role in the cases of central west (CW) and south west (SW) cyclone groups. In all other groups the positive vorticity advection factor seems to be of primary importance for the location of maximum precipitation.

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