# RELACIÓN ENTRE LAS DISTRIBUCIONES ESPACIALES DE PRECIPITACIÓN EN LAS REGIONES MEDITERRÁNEAS ESPAÑOLAS Y LA OROGRAFÍA

## *RELATIONSHIP BETWEEN THE SPATIAL PRECIPITATION DISTRIBUTIONS OVER THE SPANISH MEDITERRANEAN REGIONS AND THE OROGRAPHY*

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*SUMMARY*

From different synoptic configurations (obtaining from previous works) which produce significant precipitation in the spanish Mediterranean area (Andalucía, Murcia, Valencia, Cataluña and the Balearic Islands) we sought determining the orographic effect over the spatial precipitation distribution in such area. In order to do that numerical simulations with the regional model HIRLAM, and using as initial conditions the above-referred synoptic situations, were performed. We isolated, by means of a factor separation technique, the separate effects of the Iberian Peninsula orography, and the non-Iberian one, as well as the synergy between both orographies. Despite of the considerable diversity of atmospheric circulation patterns and their wide varity of simulated precipitation spatial distributions linked a clear distinction between Atlantic and western Mediterranean disturbances is obtained. The north African Atlas range, due to its primary influence, emerges as a ruling factor on the spatial distribution of rainfall across the Spanish Mediterranean area.

## 1. Introduction

The western Mediterranean basin is surrounded by important mountain ranges, which reach its coastline (Fig.1). This overall orography plays a major role in the configuration of the regional climate (Font, 1983), and more specifically in the spatial distribution of rainfall Romero et al. (1999a).

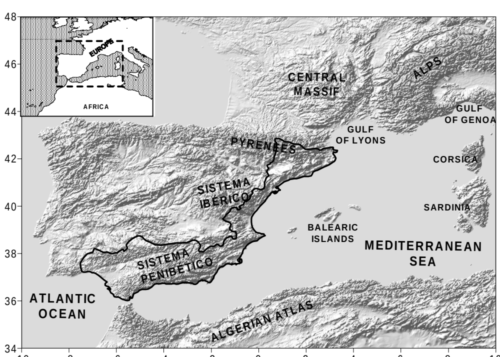


Fig.1- The Western Mediterranean. Bounded region represents the Spanish Mediterranean zone.

Romero et al. (1999b) have shown that precipitation in the Spanish Mediterranean area (Fig.2) occurs under certain synoptic situations. In fact, using ECMWF data from 1984-1993 they found, through cluster analyses, 19 atmospheric patterns, which produce significant precipitation. In addition, they show that these atmospheric patterns corresponded closely to 11 precipitation pattern groups since each of the atmospheric patterns can be associated with a few precipitation pattern groups. They also show that interaction between orography and synoptic flux could explain, at least partially, the spatial distribution of precipitation.

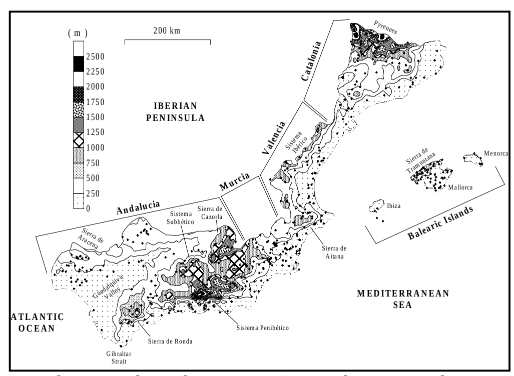


Fig.2- The Spanish Mediterranean Area and its orography

The main goal of this study is to determine the orographic effect on the precipitation field in the Mediterranean Spain. A secondary, but not less important, objective consists on isolating the respective influence of the Iberian orography on such field as distinct from the external orography, paying special attention to the effect of the Atlas and the Alps range, because of their already demonstrated main role in the Mediterranean weather.

To manage these objectives we have performed a set of numerical simulation using the HIRLAM model for different synoptic situations, one per each of the 19 atmospheric pattern which, according to Romero et al (1999b), have been shown to produce significant rainfall in the region.

The factor separation technique of Stein and Alpert (1993) allows us to quantify not only the separate effect of Iberian and non-Iberian orography but also the effect of interaction between them.

In section 2 we briefly describe the methodology and the general approach towards the numerical simulations. Some preliminary results are presented in section 3. Conclusions are provided in section 4.

## 2. Methodology and general approach

In order to perform the aforementioned numerical simulations of each atmospheric pattern, we first selected a real meteorological situation representative of each atmospheric pattern, in other words, we selected the day from each pattern-defining cluster that showed the most similar structure to its corresponding composite (cluster's centroid). To make the decision of which day is the most similar, we used a method based on correlation analysis applied to the geopotential field. Considering each atmospheric pattern separately, we defined a two-dimensional space characterised by an x-axis, which represents values of correlation between a single day and the composite at 500 hPa, and an y-axis, representing the same at 925 hPa. The region for which these correlation values were calculated is the same one used by Romero et al. (1999b) to compose the clusters. Then, taking an Euclidean distance operator, the distance of each day to the composite (point (1,1) in the two-dimensional space) is:

$$D_i = ((1-x_i)^2+(1-y_i)^2)^{1/2} \qquad (1)$$

Where $x_i$ and $y_i$ are correlation values between the geopotential field of a single day (i) and its composite at 500 hPa and at 925 hPa respectively.

Therefore, the day, which presents the minimum value of $D_i$ is the closest situation to the composite, and then it is selected as the representative day of the cluster.

The simulations were performed with the hydrostatic numerical model HIRLAM. This model is horizontally formulated for an Arakawa C-grid whereas the vertical formulation corresponds to the hybrid system used at ECMWF (31 p-$\sigma$ vertical levels). Prognostic equations for the horizontal wind, temperature, surface pressure and moisture, besides an additional equation for cloud liquid water are solved. An Eulerian semi-implicit time scheme was used. A fourth order explicit linear horizontal diffusion scheme is implemented on every prognostic variable but liquid cloud water.

Further information about the model configuration as well as about the different parameterization schemes used is given in Sotillo et al. (2000).

Simulations were performed over the region 31.65°N-48.75°N and 18.00°W-12.30°E (Fig. 3), centred in Mediterranean Spain. Numerical experiments were done with a horizontal resolution of 0.3°x0.3°. That means a cell size of roughly 30x30 $Km^2$ and a grid of 102.58 points. Vertically, 31 hybrid levels were considered. The used time step for the model integration was 90 s. Non-initialized ECMWF analyses, with 0.75° resolution and available at 0000, 0600, 1200, 1800 UTC, were used like boundary conditions. We extended our simulations for a 30-hour period (T+30) to include a spin-up initial period. Then, simulations start at 0000 UTC and end next day at 0600 UTC, but precipitation is only considered from 0600 UTC to 0600 UTC the next day.

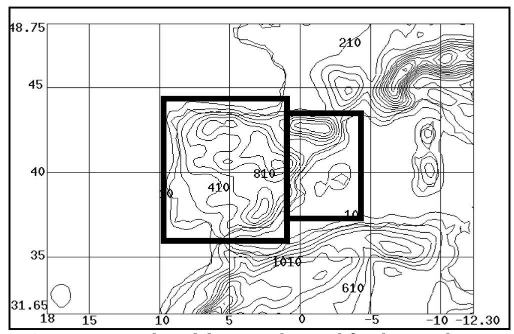

Fig.3 - Domain and model orography used for the simulations.

In order to isolate the respective influence of the Iberian orography on the precipitation field as distinct from the external one, we used the factor separation technique of Stein and Alpert (1993). Which allow us to quantify not only the separate effect of Iberian and non-Iberian orography but also the effect of interaction between them.

Following this technique, it is necessary to performed $2^n$ simulations to isolate the effect of n factors by means of numerical simulations.

Firstly is needed a complete simulation (CS), which reveals the model capability to simulate the precipitation field of the corresponding atmospheric pattern. Secondly, a non-orographic simulation (NOS), identical to the previous one but without orography. Note how, and despite the existence of some orographic influence on the initial and boundary conditions, difference in the above simulations give us basically the role played by orography on precipitation field.

Since two factors are considered (local and non-local orographies) two more simulations are necessary in addition to the above-referred CS and NOS. One simulation including only the Iberian Peninsula orography (IPOS) and a complementary one with all the orography except the corresponding to the Iberian Peninsula and the Balearics (NIPOS).

The contributions of the different factors are calculated as it is shown in table1.

| Orographics Effects | Calculations |
|---|---|
| Whole orography | CS - NOS |
| Local orography | IPOS - NOS |
| Non-local orography | NIPOS -NOS |
| Synergism | CS - (NIPOS+IPOS) + NOS |

Table 1. - Calculations with different simulations to obtain the different individual effects.

Note that the sum of the last three contributions is equivalent to the effect of the whole orography, represented by the first effect (CS-NOS).

### 3. Results and discussion

In this section we present the results obtained for four selected cases from the whole nineteen atmospheric patterns. Results obtained for the selected atmospheric patterns are depicted in Figures 4 to 7. Each figure shows: a) the synoptic situation representing the atmospheric pattern, b) the simulated precipitation over the Iberian Peninsula and c) the effect of the whole orography on the precipitation field in Mediterranean Spain. The effects due to local orography (d), non-local orography (e) and its interaction (f) are only shown for those cases in which notable external orographic influence emerges.

The situation representative of the first atmospheric pattern shown (this is the atmospheric pattern 2 from the 19 Romero´s patterns) is characterized by a deep low pressure centre sited to the northwest of France, producing westerlies over the whole of the Iberian Peninsula (Fig 4a). It is worthy to note how the simulated precipitation is distributed over the western and northern parts of the Iberian Peninsula, mainly following the orography. However, on the Spanish Mediterranean regions, this synoptic situation hardly produces significant precipitation (fig 4b), except for some nuclei sited over Sierra de Aitana and Sistema Ibérico. Figure 4c shows that the above nuclei are due to the action of orography, and particularly to the local one.

The second atmospheric pattern shown (5/19) is characterized by a surface low-pressure system sited close to the southwestern flank of the Iberian Peninsula. A closed cyclonic circulation is present aloft. This configuration favours warm easterly flows over southern Spain (Figure 5a). The complete simulation gives widespread precipitation along the western flank of the Iberian Peninsula, with notable amounts. Focusing on the study area, Andalucía receives most of the precipitation, which is concentrated along its western and northern parts (Figure 5b). Note the remarkable positive effect, or precipitation enhancement, caused by Sierra de Aracena, as well as the dipolar rainfall structure observed over central Andalucía (Figure 5c). Local orographic factor is mainly responsible for the Sierra de Aracena nucleus, as well as for the central andalucian precipitation redistribution (Figure 5d). The non-local factor shows a negative contribution to the north of Andalucía as a consequence of a shifting of the dynamic forcing associated with the low (Figure 5e). This shifting is produced by a flow modification induced in the lee of the Atlas range. The role of the synergism for this pattern consists of a change in the impingement direction of the flow (S to SE), in such a way that northern part of Andalucía becomes exposed. Then, in that northern part, precipitation is enhanced whereas in central and southern areas of Andalucía the interaction of local and non-local orography decreases precipitation (Figure 5f).

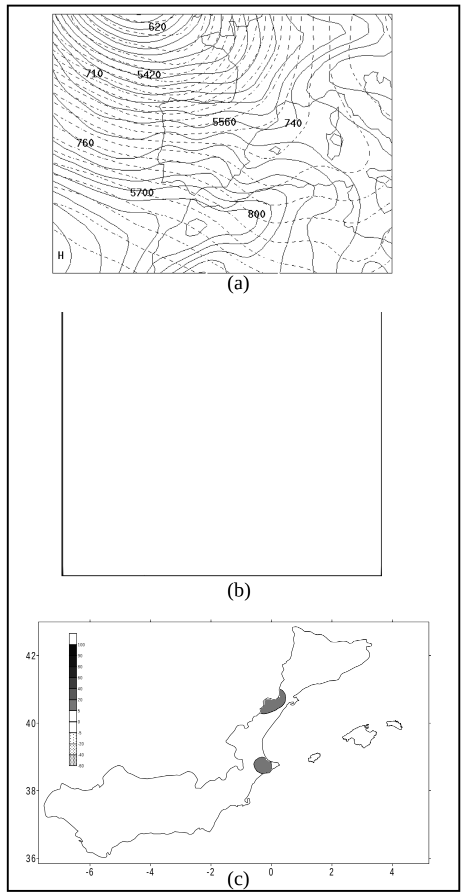


Fig. 4 - Atmospheric pattern 1: a) Geopotential field at 925 hPa (continuous line) and at 500 hPa (dashed line), contour intervals are 10 and 20 gpm respectively; b) Total simulated precipitation from 06 UTC to 06 UTC the next day (contour interval is 5 mm, starting at 5 mm); and c) total orographic effect (contours in mm as indicated in scale, areas with |CS-NOS|<5 mm are not shaded).

Next situation (6/19) showed is similar to the previous one, but in this case there is a deeper secondary surface low over the Algerian coast, with the eastern Spanish Mediterranean coast being affected by low-level easterlies (Figure 6a). The simulated precipitation field linked to this situation (Figure 6b) exhibits widespread precipitation over the southern half of the Iberian Peninsula; mainly over the whole Andalucía, with peaks over Sierra de Ronda, Sistema Penibético and a secondary peak over Sierra de Aracena. Figure 6c displays that the orographic effect consists of an enhancement of precipitation over the main peaks, but a suppression over Murcia, South Valencia and lowlands of Andalucía. Arising from this, significant precipitation in these areas linked to the dynamics of the system itself appears when the pattern occurs. Note that for this situation the simulated precipitation field comprises important contributions from every individual orographic factor (local, non-local and their interaction). The local orographic factor concentrates precipitation on the highest peaks and windward slopes of Andalucía, as well as increases the precipitation over the coastal areas. This can be explained by the lifting provided by the orography under the impingement of the low-level flow. The negative effect in central and northern Andalucía can be explained as a lee effect (Figure 6d). The non-local orographic factor under this easterly flow causes a general precipitation decrease over central and eastern Andalucía, Murcia and south Valencia. Such decrease appears to be associated with the precipitation generated over the Atlas, which consequently eliminates rainfall production further downstream (Figure 6e). Finally, the synergistic effect is significant over Andalucía. This is consequence of the wind convergences (not shown) produced as a result of the flow modification by the local orography and the Atlas range.

The last atmospheric pattern (15/19) shown in this communication displays as its major synoptic features an intense surface low pressure system over northern Africa, which induces southeasterly flow over southeastern Spain, and an upper level cut-off low to the west of the Iberian Peninsula (Figure 7a). This situation induces strong warm advection over the southeastern Spanish coast. The complete simulation for this case produces a precipitation field characterized by a wide rainfall zone crossing the Iberian Peninsula from south to north (Figure 7b). Focusing on Mediterranean Spain, inland areas of Valencia and Murcia, as well as inland ranges of eastern Andalucía (Sistema Subbético and Sierra de Cazorla) are affected. Simulated precipitation exhibits a strong dynamical component. As it can be seen in Figure 7c, orography redistributes precipitation, tending to suppress the strong dynamic precipitation nucleus (not shown) along the southeastern flank of Mediterranean Spain. Such suppression is focused on coastal areas of eastern Andalucía. At the same time this orographic action enhances precipitation over inland regions of Valencia and Murcia. However, local orography enhances precipitation over central Andalucía (Figure 7d), whereas most of the suppression is caused by the non-local orography (Figure 7e). This rainfall suppression over Andalucía is due to the action of the Atlas, which eliminates downstream rainfall. The interaction between local and non-local orographies either enhances or suppresses rainfall depending on the zone (Figure 7f). It is a consequence of the convergence or divergence of the low-level wind field induced by the pressure anomalies, which are negative in the lee of the Atlas and positive windward of the Iberian Peninsula (not shown).

## 4. Conclusions

The results illustrate that orography is a key factor for the spatial distribution of precipitation over Mediterranean Spain. It is explicitly shown that the complex orography favours the precipitation on highlands exposed to the airflow and therefore a reduction of precipitation on surrounding sheltered lowlands. For most of the precipitation-producing atmospheric scenarios, analysed in the study, the orographically-enhance precipitation, and especially over the ranges, represented almost all their total simulated precipitation.

Regarding individual contributions of local and non-local orography as well as their interaction, a clear dependence on the meteorological situation appears.

A clear distinction between Atlantic and western Mediterranean disturbances is obtained. In fact, when a low pressure system lies to the west or north-west of the Iberian Peninsula, producing humid Atlantic flows over it, local orography generally emerges as the unique significant factor (correlation values between the effect of the total and the local orographies greater than 0.9). On the other hand, when easterly flows at low levels appear over Mediterranean Spain, the effects of non-local orography and synergism become relevant, with a remarkable role of the Alps (not shown) and the Atlas ranges. Even though, the local factor also affects crucially for these situations by redistributing precipitation through the aforementioned mechanisms, the remote action of the Atlas results in a precipitation decrease over southern Mediterranean Spain. This effect is especially important when the upper level flow is from the south-southwest, and a surface low develops in response to the lee of the Atlas Mountains over the Algerian coast. The interaction between local and non-local factors is also significant in these cases. Effectively, modification of the low-levels flux by the action of the Atlas and the resultant modified impingement on the Iberian orography relocate divergence/convergence zones and thus induce a redistribution of precipitation.

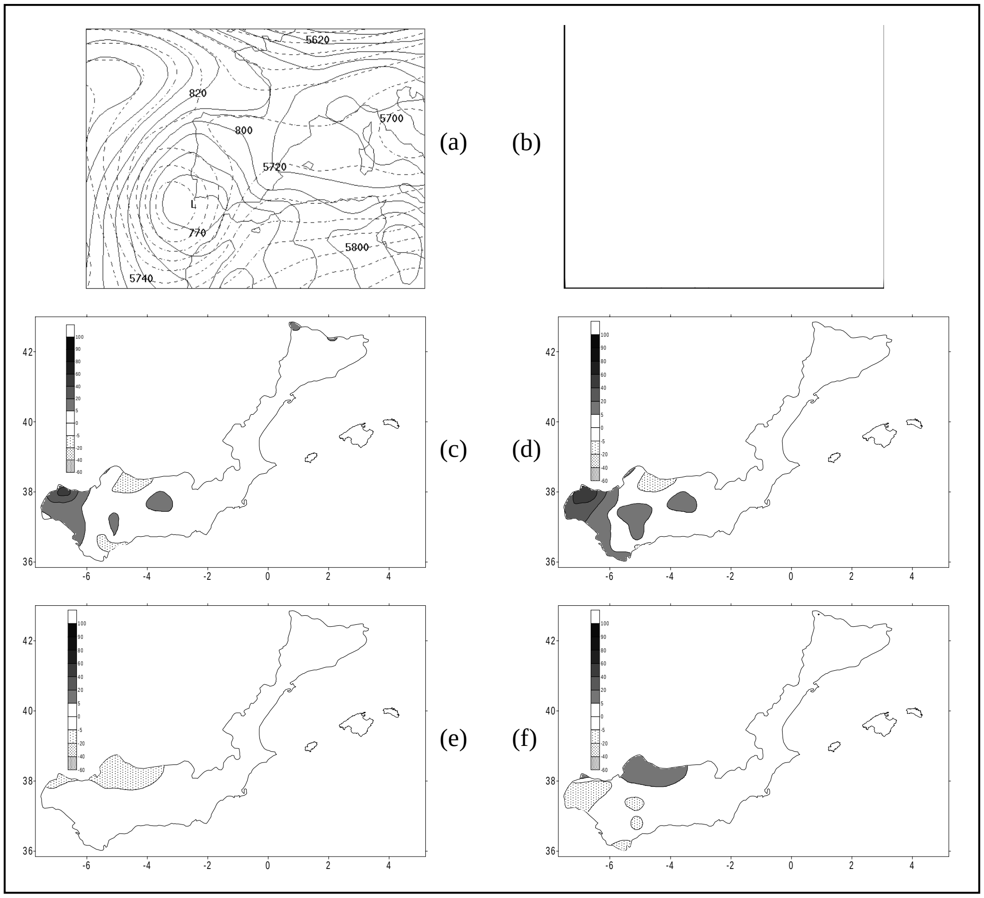


Figure 5.- Atmospheric pattern 2: a), b), and c) as in Figure 4; d) Local orographic effect (contours in mm as indicated in scale, areas with |IPOS-NOS|<5 mm are not shaded); e) non-local orographic effect (contours in mm as indicated in scale, areas with |NIPOS-NOS|<5 mm are not shaded); and f) synergistic effect (contours in mm as indicated in scale, areas with |CS-(IPOS+NIPOS)+NOS|<5 mm are not shaded).

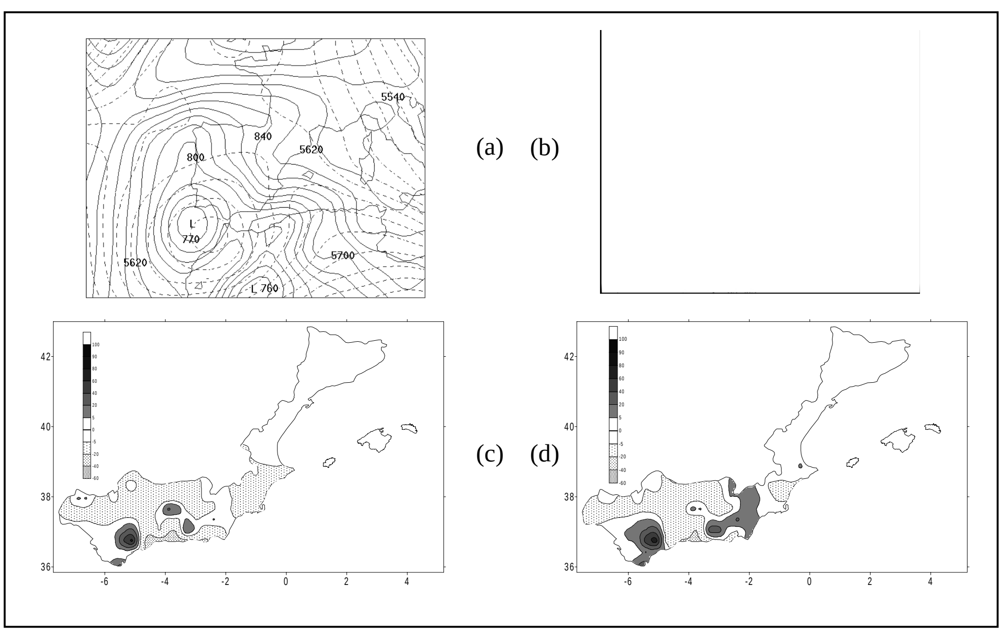


Figure 6.- e) and f) pictures and figure caption in next page.

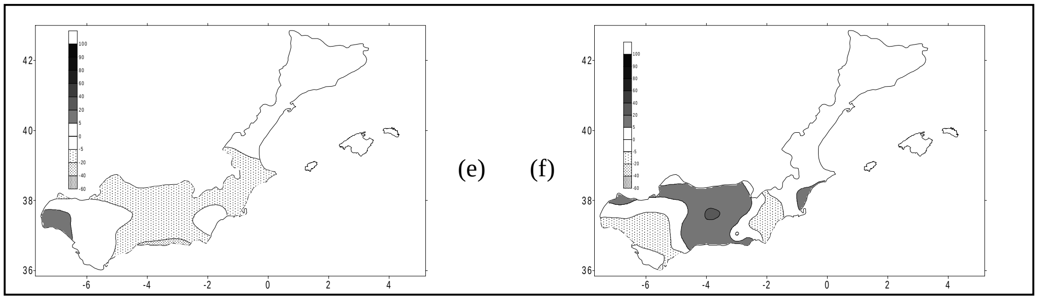


Figure 6.- Atmospheric pattern 3: a), b), c), d) (shown all of them in the previous page), e) and f) as in Figure 5

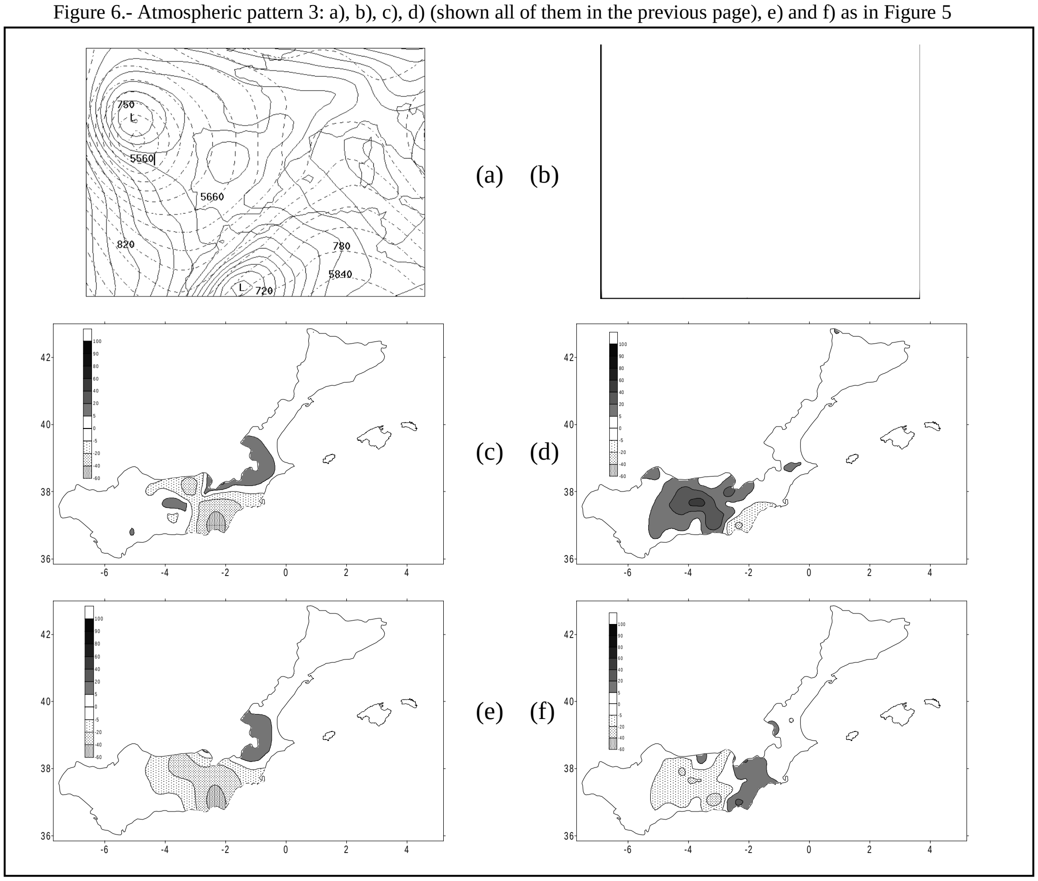


Figure 7.- Atmospheric pattern 4: a), b), c), d), e) and f) as in Figure 5

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