IBERIAN SUMMER PRECIPITATION MODES OF VARIABILITY AND EXTREME EVENTS

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ABSTRACT

Summer precipitation variability in the Iberian Peninsula is not a very common issue in the scientific literature. In general, Iberian precipitation variability is more frequently studied for the coldest seasons (autumn and winter). Summer is often related with the absence of precipitation and sunny days, especially in the southern regions. However, Summer precipitation it's a non-neglectable phenomenon, not only on the northern Iberian mountains but also on the southern plains. Variability over the 20th Century of summer precipitation in the Iberian Peninsula is studied using a high resolution data set. Rotated Principal Component Analysis (RPCA) was applied on summer monthly means to retain the main spatiotemporal modes for each summer month (June, July and August). The principal component (PC) of each spatial mode is analyzed to search for extreme events. Since low values of precipitation in summer are very common, an extreme event is defined as unusual positive anomalies. Results show that precipitation variability is more complex in summer months, due to the larger number of significant modes and less explained variance. Local factors seem to play a more significant role, explaining larger amounts of variance in summer. Three sets of precipitation spatial patterns could be indentified related with their geographical location: the Atlantic patterns (Western Iberia), the Mediterranean Patterns (Eastern Iberia), and the interior patterns (interior regions in northern or southern Iberia). The more intense summer precipitation events are associated with the interior patterns. The atmospheric context shows that these precipitation extreme events are associated with an unusual continental warming linked with an upper-level trough. Therefore, heavy summer precipitation events are recurrently related to thermodynamic processes. Rainfall is concentrated both in space and in time that is to say, in small regions and in short periods of time. In some cases the monthly total amount of precipitation could be registered in only one episode with the duration of a few hours. These catastrophic rains can cause flash floods and severe erosion problems. Some case studies are analyzed to illustrate the intensity of these events.

Key words: Precipitation variability, modes of variability, summer, Iberian Peninsula, heavy precipitation events

1. INTRODUCTION

The typical Mediterranean climate is characterized by a wet winter and a dry summer. Additionally winters are fresh and the summer season is hot. The high summer temperatures and the absence of rain cause a great deal of stress on the local vegetation. However, extreme summer precipitation events are not rare in the Iberian Peninsula, and most of these events are responsible for major problems related to soil erosion, thus not favorable to agricultural activities.

Numerous works pointed out to the importance of summer cyclonic activity due to the formation of a thermal low and the advection of warm and humid air from the Mediterranean (SORIANO, 2001b, and TOMÁS, 2004, for example). It is well known that the continental warming in summer season plays an important role explaining severe thunderstorms, cyclonic activity (TOMÁS, *et al.* 2004) and associated heavy rainfall, concentrated in space and time. SORIANO *et al.* (2001b) focused their work in the summer season because they found that the major convective activity (according to the recorded number of flash floods) occurs in summer, between June and August. Local factors such as orography play an important role explaining the spatial distribution of flash floods (SORIANO *et al*., 2001a), thus the convective activity.
In this study we test if Rotated Principal Components Analysis (RPCA) can in fact isolate the main spatiotemporal modes that could be related with summer precipitation extreme events in the interior of the Iberian Peninsula. Our assumption is that if convective activity is very important in summer in the interior regions of the Iberian Peninsula, PCA must detect precipitation modes of variability associated with these cyclonic episodes.

2. DATA AND METODOLOGY

Precipitation data for the Iberian Peninsula were extracted from a high resolution gridded dataset made available by the Climate Research Unit (CRU) (NEW *et al*., 2000). The data was interpolated on a 0.5º grid and is available for all continental areas except Antarctica. Each spatial point consists of a time-series spanning the period 1901-1998. 324 points were extracted from this dataset for the Iberian Peninsula.

Atmospheric data came from the NCEP/NCAR Reanalysis (KALNAY *et al*., 1996) with data available after 1948. Although this study focus on summer (JJA) we decided to applied Rotated Principal Components (RPCA) to all months of the year in order to compare results with SERRANO *et al.* (1999) and also to put the summer season in contrast with the rest of the year.

RPCA was then used to extract the main spatiotemporal modes for summer precipitation. RPCA was applied to twelve different matrices containing precipitation data for the Iberian Peninsula. So for each month a different RPCA is applied, following the methodology in SERRANO *et al.* (1999). Data were standardized prior to PCA.

Precipitation patterns are the PCA's eigenvectors and Principal Components (PCs) illustrate the patterns temporal variability. The PCs could be retained to further analysis, namely for constructing composite maps either to test the physical meaning of the PCA patterns (precipitation composite maps) or to build composite maps to study the atmospheric context of a specific precipitation pattern. An extreme precipitation event is defined as an unusual positive value on the PC.

3. RESULTS

RPCA results show that precipitation variability in summer is much more complex in comparison with the rest of the year due to a larger number of PCs retained as significant, according to the test developed by NORTH *et. al.*(1982). In general these results are in agreement with previous ones, namely those obtained by SERRANO *et al.* (1999). The spatial structure of the eigenvectors (precipitation patterns) is very similar, although we detect some differences, namely the absence of summer interior modes in SERRANO *et al.* (1999). These authors have identified only one interior mode that reflects the variability of all the interior region of the Iberian Peninsula but this mode only occurs in Spring and Autumn. These differences are probably due to the sensitivity of PCA to changes in space and time domains. SERRANO et al. (1999) use a different data base (data were collected from Iberian stations, so not a gridded dataset) that covers a different time period.

In the present work we have identified three sets of patterns, according to the geographical location of the values that indicate higher variability (higher correlations of the eigenvectors): Atlantic patterns, the Mediterranean patterns and the interior patterns.

The Atlantic patterns have their higher correlations located in the Atlantic regions of the SW (SW Pattern), NW (NW pattern) and, finally, in the northern Iberia (Cantabrian Mountains pattern – CM).

The Mediterranean patterns illustrate the precipitation variability along the eastern Mediterranean seaboard. There are two major patterns: the NE pattern and the SE pattern. The first one reflects the variability of the Catalonian region while the second the variability of the region of Múrcia/Almeria.

Finally, the interior patterns that reflect the variability of interior regions of the Iberia Peninsula: Interior Centre (IC), the Interior NW (INW), interior SE (ISE), and Interior NE. IC occur only in spring and INE was identified from May to September. Only INW and ISE are typically summer patterns, because they only occur in June, July and August. These two patterns are the focus of our study. Their characteristics drew our attention because they are not present in SERRANO *et al.* (1999) work and only occur in summer (JJA). Thus in the next sections these patterns are analyzed in more detail in order to test their physical meaning, their association with the summer cyclonic activity, and their relation to extreme precipitation events.

3. 1. Typical summer rainfall patterns

The PCA results revealed two distinctive and typical summer patterns: the first one we called “Interior NW” (INW) and the second one “Interior SE (ISE). Although both their variance explained and eigenvalue order is relative low when compared to the other patterns (Figure 1). They illustrate the precipitation variability of very restricted areas in the interior of the Iberian Peninsula.

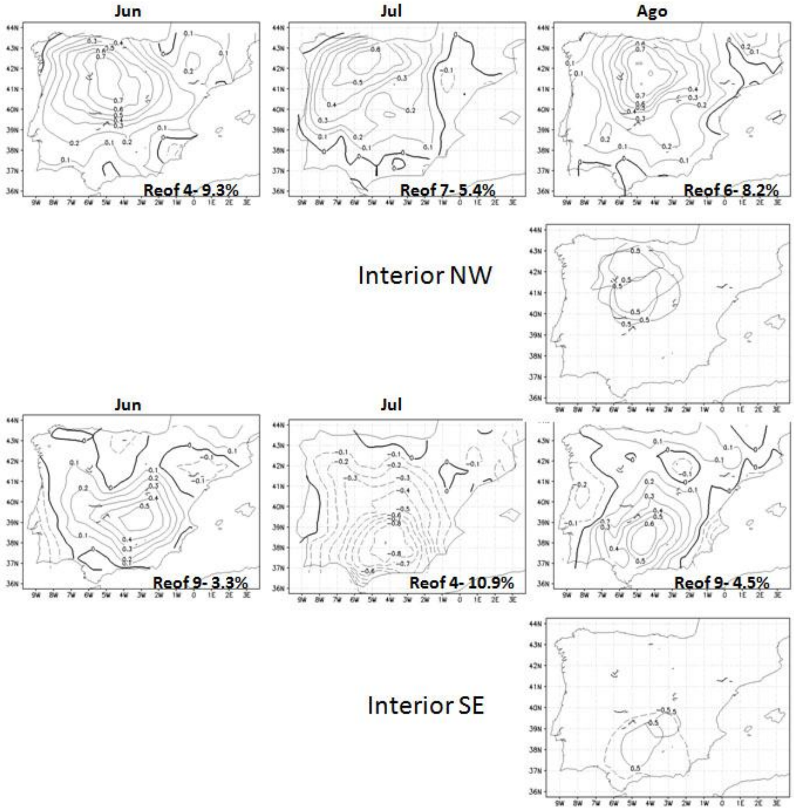

Figure 1 – Rotated EOF's of the interior patterns (INW and ISE) from June to August. The maps at the bottom of each pattern indicate the area of the 0.5 correlation

In general the INW pattern has a greater statistical significance than its southern counterpart. The core of this pattern is located between the northern mountains (Cantabria and Asturian regions) and the mountains of the Central System, spanning parts of the Northern Meseta.
The ISE pattern defines the precipitation variability in the Guadalquivir, Sierra Morena and the south eastern Iberian mountains in the "Cordilleras Béticas".

The physical meaning of these patterns is tested in Figure 2, where two composite maps are displayed based on the highest indices of the principal components. The units are precipitation anomalies relative to the 1900-1998 average. The anomaly patterns resulting from the composites reveal the same spatial structure of the rotated EOF's, so we can assume that these patterns have a physical meaning.

4. 2. The atmospheric context of the interior patterns

Composite maps of Sea Level Pressure (SLP), 500 hPa geopotential height (Z500) and air temperature were made, based on the highest indices of the RPC in order to enhance the climatic signal. These maps indicate the average of the atmospheric variables in months associated with each precipitation pattern (INW or ISE). A brief analysis show that these patterns are associated with thermo dynamical conditions: the formation of a low pressure

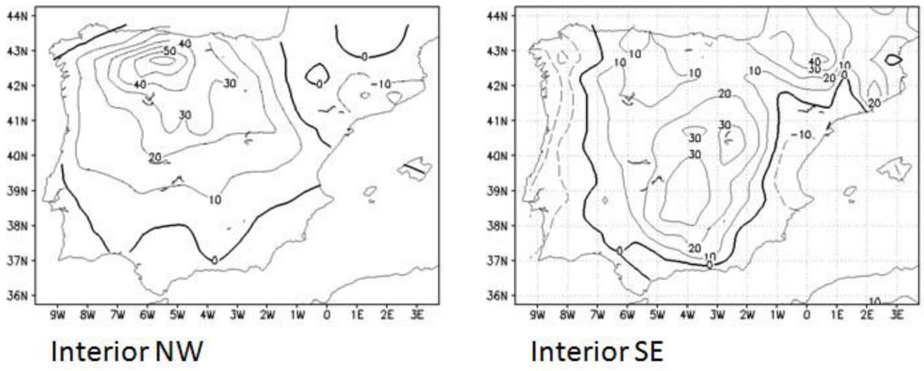

Figure 2 - Composite anomaly maps keyed to the highest indices of the RPC

system at the surface in the interior of the Iberian Peninsula (due to the warming of the continent and the arrival of hot Saharan air), followed by an upper-level trough in altitude, usually above Z500.

An example of the atmospheric context for the interior patterns is presented in Figure 3. For both patterns we can clearly see by the analysis of surface pressure and wind components the formation of a low pressure in Iberia. Simultaneously an upper-level trough is formed in the upper layers of the atmosphere. The air temperature pattern at the surface and at Z500 gives us additional information concerning the thermo dynamical conditions: warm air “invades” the Iberian Peninsula at the surface and cold air comes above it at Z500, which generate great atmospheric instability.

In the ISE pattern the atmospheric context is very similar but the upper-level trough seems to be located a little bit more to the east.

4. 3. Analysis of some case studys

This section concerns the characterization of two extreme rainfall events in order to illustrate the relevance that summer rainfall could achieve, in certain years, to the precipitation regime in the interior regions of Iberia. The rotated PCs give us the first information on months with extreme events. First we choose to identify extreme events as months with the highest indices on the RPCs (Figure 4). In the case of the INW pattern we have identified July 1979 as a month which can illustrate an extreme event. The spatial precipitation pattern shows that the larger anomalies occur in the northern Iberian mountains and in central Portugal. For the ISE pattern we have found three major extreme events, nonetheless our choice was August 1952. In the anomalies spatial pattern we can see that major anomalies arise in the interior of the Valencia Region

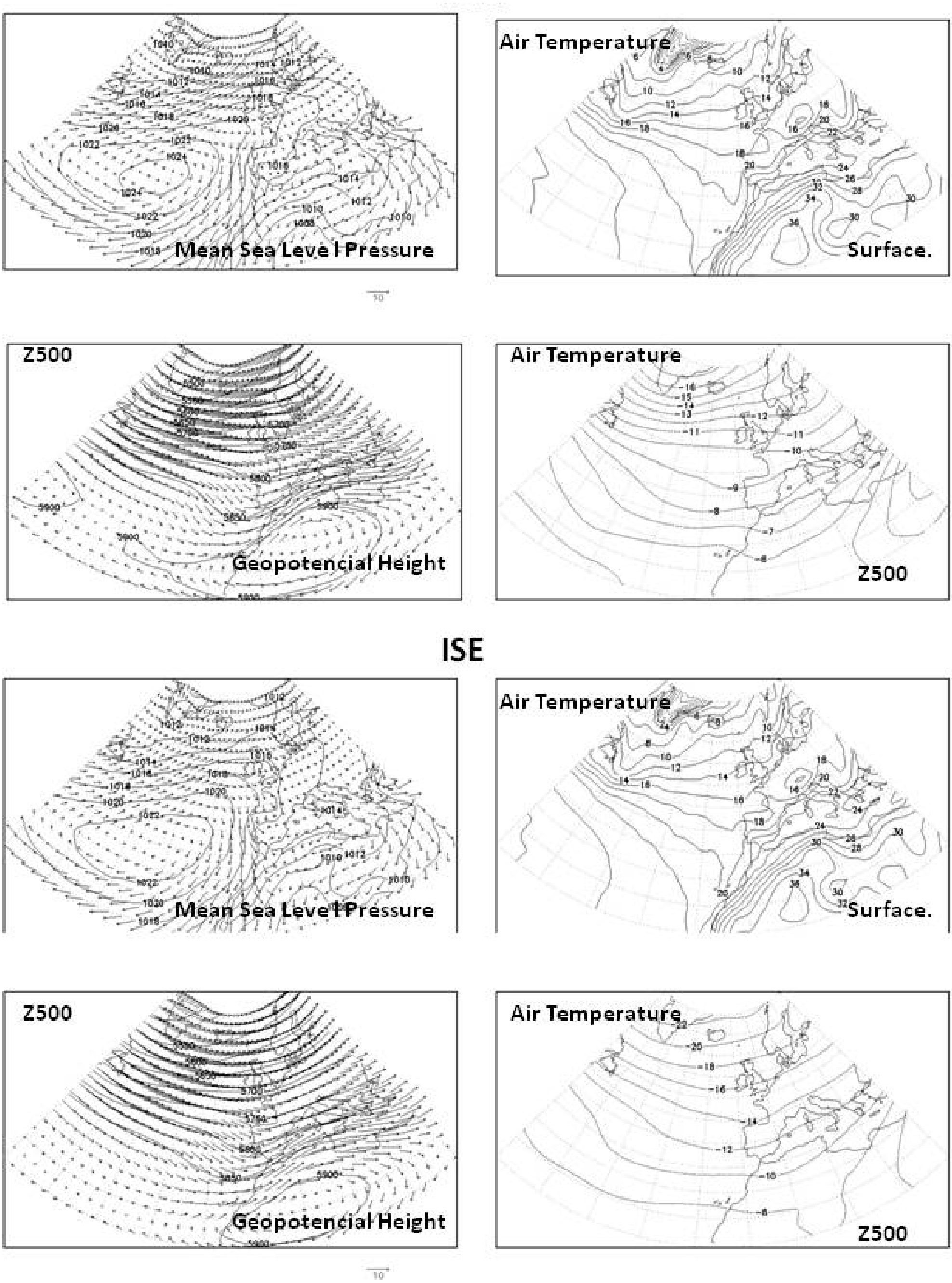

Figure 3 – Composite maps of SLP, Z500 and air temperature (at surface and Z500) keyed to the highest indices of the precipitation RPCs for the INW (above) and ISE (bottom).

Using the reanalysis data we have confirmed the selection of particular months with correspondent rainfall (positive) anomalies over the Interior-Southeast regions or over the Interior-Northwest areas, procedure that allowed isolating, respectively, August 1952 and July 1979 as interesting «ideal» cases. The monthly evolution of the weather conditions in the two reanalysis grid points, with approximately central location in relation to the mentioned regions, was then analyzed, examining meteograms (not shown in this paper). In both selected months, it was concluded that the rainfall occurred with a highly concentrated character, with almost the total monthly precipitation being observed in two days or even in just a single day.

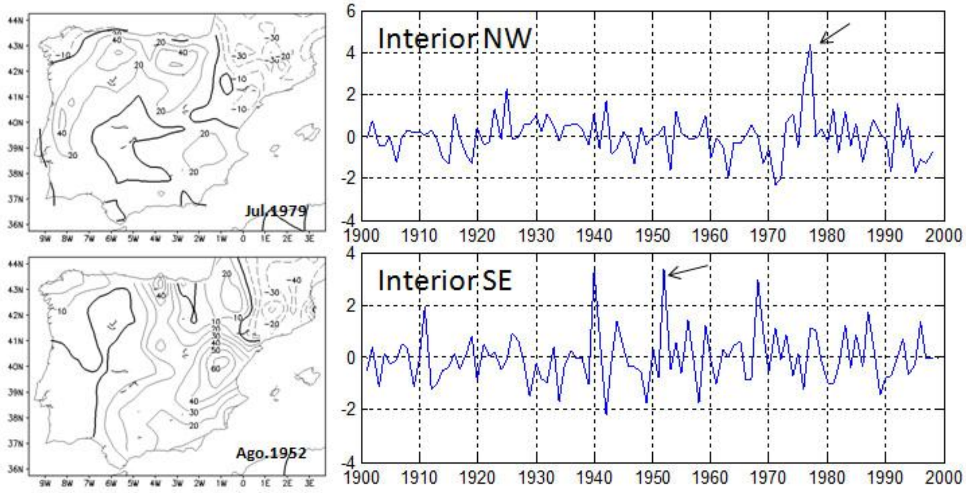

Figure 4 – Extreme events identified by the Rotated Principal Components (right). The arrow indicate de highest index and the maps (on the left) show the spatial distribution of rainfall anomalies (mm)

4.3. a. ISE rainfall pattern event: 28th August 1952

In the 27th and 28th August 1952, the eastern and southern regions of Spain were affected by very intense precipitation. The most notable rainfall amount was measured in Puebla de Valverde (Southern Teruel province), where 400 mm/24 h were reached. Precipitation records exceeding 100 mm/24 hours were also registered in different sites of Valencia province, like Alaquàs (138 mm), Montroy (128 mm), Llombay (120 mm) and Benaguacil (102 mm)[14]. As it can be observed in figure 5 (A to F), this extreme rainfall event was controlled by the influence of a cut-off low system (COL). These systems are slow moving and often stay over the same region for several days, therefore capable of considerably affecting the weather conditions felt at the surface (Nieto et al., 2007). Using reanalysis-1 data[15], we have found that this rainfall event was triggered by thermodynamic processes. After the 26th August, COL has moved into

[14] Source: Boletín Diario del Servicio Meteorológico Nacional, Ministério del Aire, España

[15] Source: NCEP/NCAR reanalysis data accessed in the National Operational Model Archive Distribution System website (www.nomads.ncep.noaa.gov)

the Western Iberia, transporting cold air at the middle and upper layers of the troposphere. Simultaneously, the location of the surface cyclone (non-frontal), centred in the southern part of the peninsula and its connection with the large thermal low placed in Northern Africa (Figure 5-A), was responsible for a strong increase of the instability. At the lower levels, the flow transported large amounts of moisture (Figure 5-E), taking into account its track over the Mediterranean Sea and the warm temperatures of the associated air mass (near or exceeding 30ºC at 925 hPa, in Figure 5-B). Thus it becomes clear the importance of the easterly circulation and the location of the COL system for the increase of the instability and the development of strong convection over the eastern part of the Iberian Peninsula. The computation of CAPE (convective available potential energy) for the reanalysis grid point located at 40ºN and 2º30´W has resulted in value of 2290 J/Kg[16], an amount that is consistent with the large area of lifted index values below – 4ºC (Figure 5-F), suggesting the strong likelihood for severe thunderstorm activity.

4.3. b. INW rainfall pattern event: 11 and 12th July 1979

This event was related with a similar synoptic circulation pattern, however the origin of the air flow associated with the intense rainfall generation came from the Atlantic area. In the prior days of the event, a cut-off low has formed over the Eastern Atlantic, and staying to the west of Portugal since the 7th to the 10th July. During this period, anticyclonic conditions prevail under the Iberian Peninsula, which have allowed the occurrence of sunny and warm weather. On the 10th July, a thermal low has formed at the Southwest regions of IP, favouring the advection, at the lower levels, of moist and warm flow from the Cadiz Gulf area. In Figure 6-A and E, it could be confirmed that, on the next day (11th July), an important advection of warm and moist flow was still in progress.

A significative change in the weather conditions in IP happened on the 11th July, because the cold pool has displaced to East, as it is represented in Figure 6-C. This evolution was responsible for a sudden and strong increase of the tropospheric instability over Western Iberia, leading to convective cloud systems formation. The most affected areas by the intense rainfall, as it is suggested in Figure 6-F, were the provinces of León, Asturias and Cantabria. The highest daily precipitation values (from 6.00 am of the 11th to 6.00 am of 12th July) mentioned in the daily weather report[1] were 116 mm in Asturias (Asturias), 80 mm in Oviedo (Asturias) and 50 mm San Sebastian/Igueldo (Cantabria).

5. CONCLUSIONS

RPCA was able to isolate modes of variability related to summer convective activity. Four interior modes were identified. Only two of them were considered to be typical of summer cyclonic activity: Interior NW and Interior SE. Although SORIANO *et al.* (2001b) considered that the convective activity is higher over the Mediterranean coast, we found that INW explain larger amounts of variance than ISE, more influenced by the warm and humid Mediterranean air. The orography plays an important role defining theses modes and associated extreme events. Large amounts of rain are recorded in the interior mountains of the NW and SE. So the thermodynamic conditions are reinforced by orography.

[16] It was used Grads software for this calculation.

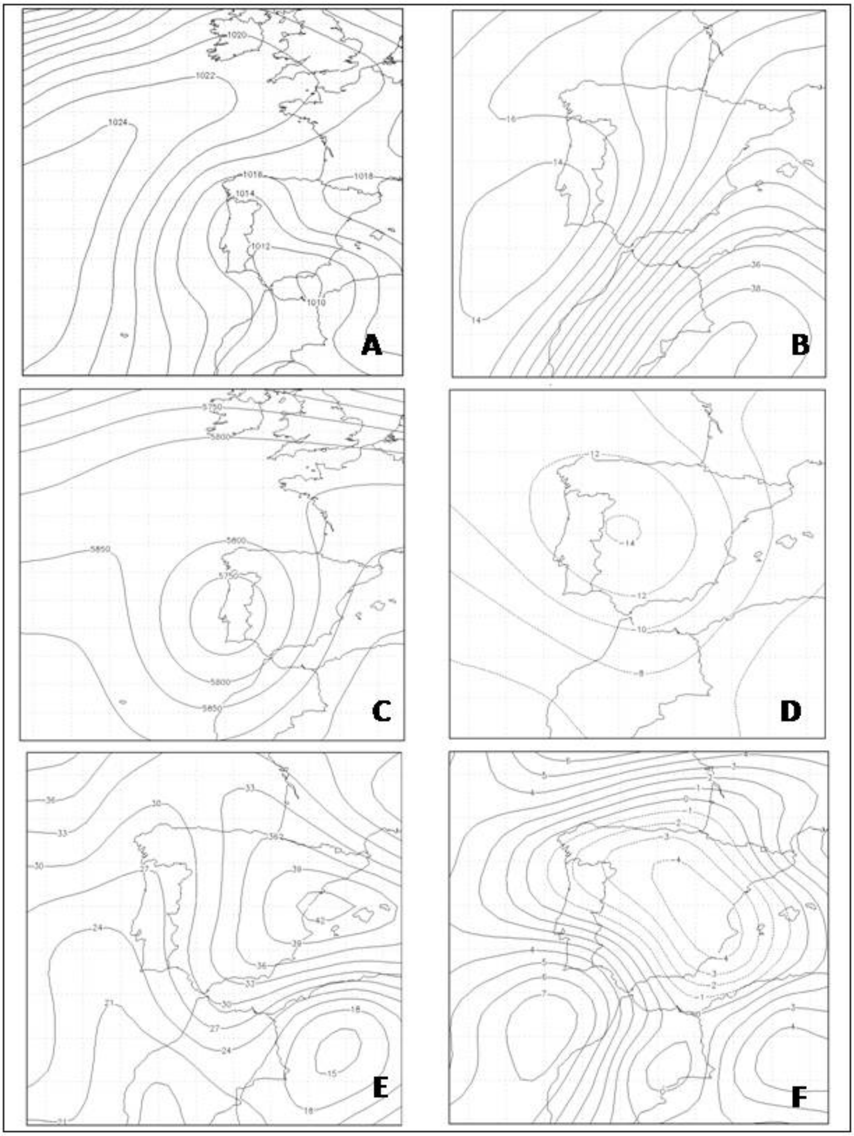

Figure 5 – The Cut-off low system affecting the Iberian Peninsula, 28th August 1952. (A) sea level pressure (hPa, 6.00 p.m); (B) air temperature at 925 hPa (ºC, 6.00 p.m); (C) 500 hPa geopotential heights (m, 6.00 p.m); (D) air temperature at 500 hPa (ºC, 6.00 p.m); (E) precipitable water (mm/day, 6.00 p.m); (F) surface lifted index (ºC, 6.00 p.m).

RPCA was found to be very useful identifying extreme precipitation events, namely for the modes that describe the summer precipitation variability in the interior regions of the Iberian Peninsula. The highest indices of the RPCs for these interior modes (INW and ISE) are associated with extreme precipitation events. The modes INW and ISE were the focus of our study and they are the only typical summer modes. They occur only between June and August

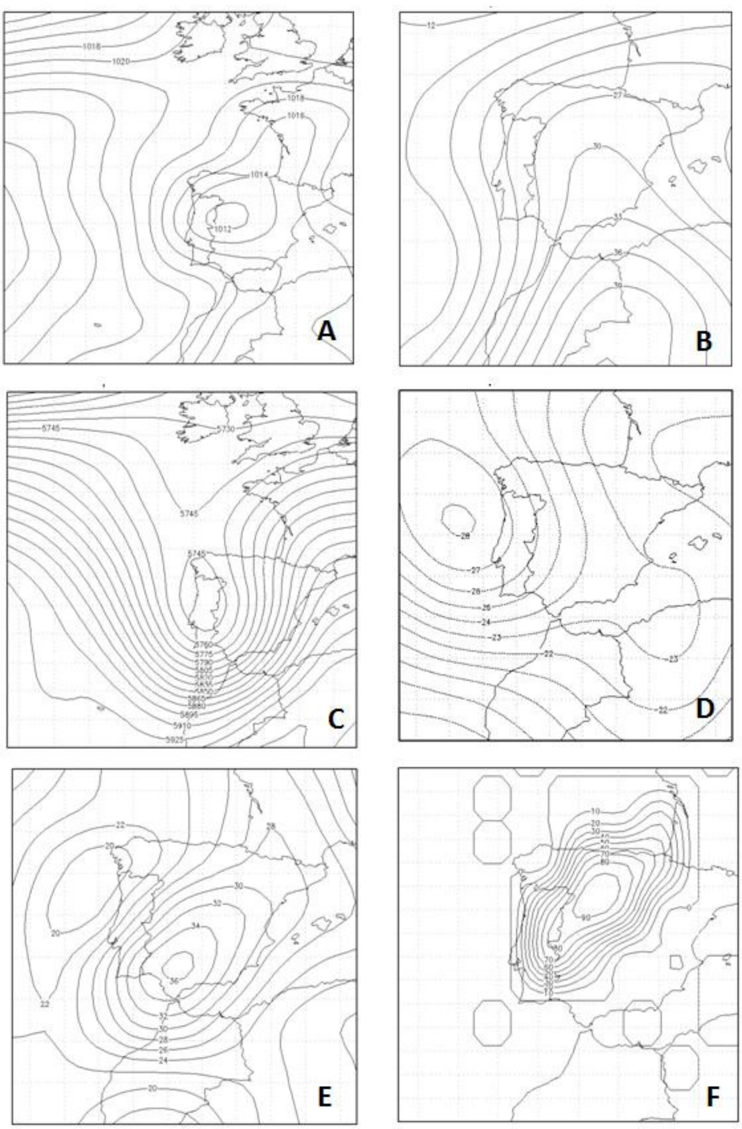

Figure 6 – The cut-off cyclone system affecting the Iberian Peninsula, 11th July 1979. (A) sea level pressure (hPa, 0.00 p.m, 11th July 1979); (B) air temperature at 925 hPa (ºC, 6.00 p.m, 10th July); (C) 500 hPa geopotential heights (m, 6.00 p.m, 11th July); (D) air temperature at 400 hPa (ºC, 6.00 p.m, 10th July); (E) precipitable water (mm/day, 0.00 p.m, 11th July); (F) surface precipitation rate (mm/day, 0.00 p.m, 11th July).

and are associated with thermo dynamical conditions. These conditions are very common in Iberian summer season. The formation of a thermal low associated with an upper-level trough is responsible for a great deal of atmospheric instability, which causes intense rainfall over the interior regions.

So the question is: which conditions generate a INW and a ISE pattern? After analyzing several composites maps, like the ones in Figure 3 and other atmospheric variables (not shown) we believe that small changes in the location of the thermal low and the upper-level trough could generate distinctive precipitation spatial distributions, associated with INW or ISE.

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