**Advances in
Science and
Research**

Heavy rain events in the Western Mediterranean: an atmospheric pattern classification

C. Martínez, J. Campins, A. Jansà, and A. Genovés

Centro Meteorológico en Illes Balears, Instituto Nacional de Meteorología, Spain

Abstract. Heavy rain is one of the most important high-impact weather phenomena that occasionally affect Mediterranean areas. The aim of this study is to achieve a classification of atmospheric patterns related to heavy rain events in both French and Spanish Mediterranean regions. The classification is made on some atmospheric fields (geopotential at 1000 hPa and at 500 hPa and temperature at 850 hPa) of HIRLAM-INM-0.5° operational analysis, for heavy rain events included in the High Impact Weather MEDEX database. It covers a period of roughly 7 and a half years, from January 1997 to May 2004. A Principal Components Analysis was conducted to reduce the number of variables. After that, by means of a Cluster Analysis, the heavy rain events are classified into 8 atmospheric patterns. The results show a good relationship between regions affected by heavy rain and atmospheric patterns, in the sense that the same atmospheric patterns usually produce heavy rain in different regions, and heavy rain in different regions is usually due to specific atmospheric patterns.

1 Introduction

Although Western Mediterranean areas are usually well-known for their pleasant weather, severe weather phenomena can occasionally affect these regions. Due to the particular topography of the area, with high mountains surrounding the Mediterranean Sea, heavy rain events can produce natural hazards, like flash-floods or landslides, with important consequences for human life.

The relationship between atmospheric patterns and precipitation has been widely studied for many regions in Europe (Trigo and DaCamara, 2000; Plaut et al., 2001; Esteban et al., 2005) and more specifically in the Mediterranean (Romero et al., 1999; Houssos and Bartzokas, 2006; Lana et al., 2007). From another point of view, the statistical relationship between heavy rain events and cyclones is studied in Jansà et al. (2001) and Campins et al. (2006).

This study forms part of the MEDEX project, whose main objective is to improve knowledge and the short-forecasting of the cyclones that produce high-impact weather in the Mediterranean (see http://medex.inm.uib.es). The specific purpose of the present study is to obtain an atmospheric pattern classification of a set of heavy rain events which affected the Spanish and the French Mediterranean regions.

2 Data and methodology

The Heavy Rain (hereafter, HR) data comes from the MEDEX database for High-Impact Weather. The database contains the HR and strong wind data registered around the Mediterranean areas. For MEDEX, HR events are defined as ones in which at least 60 mm of precipitation are recorded at any meteorological stations in a pluviometric day (24 h, from 07:00 UTC of day D to 07:00 UTC of day D+1).

For this study, the Spanish and French Mediterranean regions are selected. For a 7-year period from January 1997 to May 2004, there are records at 5830 pluviometric stations. The regions are, in Spain, Eastern Andalusia (AOR), Aragon (ARN), the Balearic Islands (BAL), Castilla la Mancha (MCM), Catalonia (CAT), Murcia (MUR), and Valencia (VAL); in France, Corsica (CO), Cote-d'Azur (CA), Languedoc-Roussillon (LR), Eastern Midi-Pyrenees (MP), Provence-Alpes-Sud (PA), and Southern Rhone-Alpes (RA), (see Fig. 2 for an approximate location). Owing to the large area over which the stations are sited and the large number of records within the 7-year period, for this study a "HR event" is redefined as the one in which at least 60 mm/24 h of precipitation is registered at 4 or more meteorological stations. According to the new definition, there are 472 HR events, which means an average of 63 HR events per year. The highest frequency of the events corresponds to autumn (39% of all cases, see Table 1).

Correspondence to: C. Martínez
(cristina.martinez@inm.es)
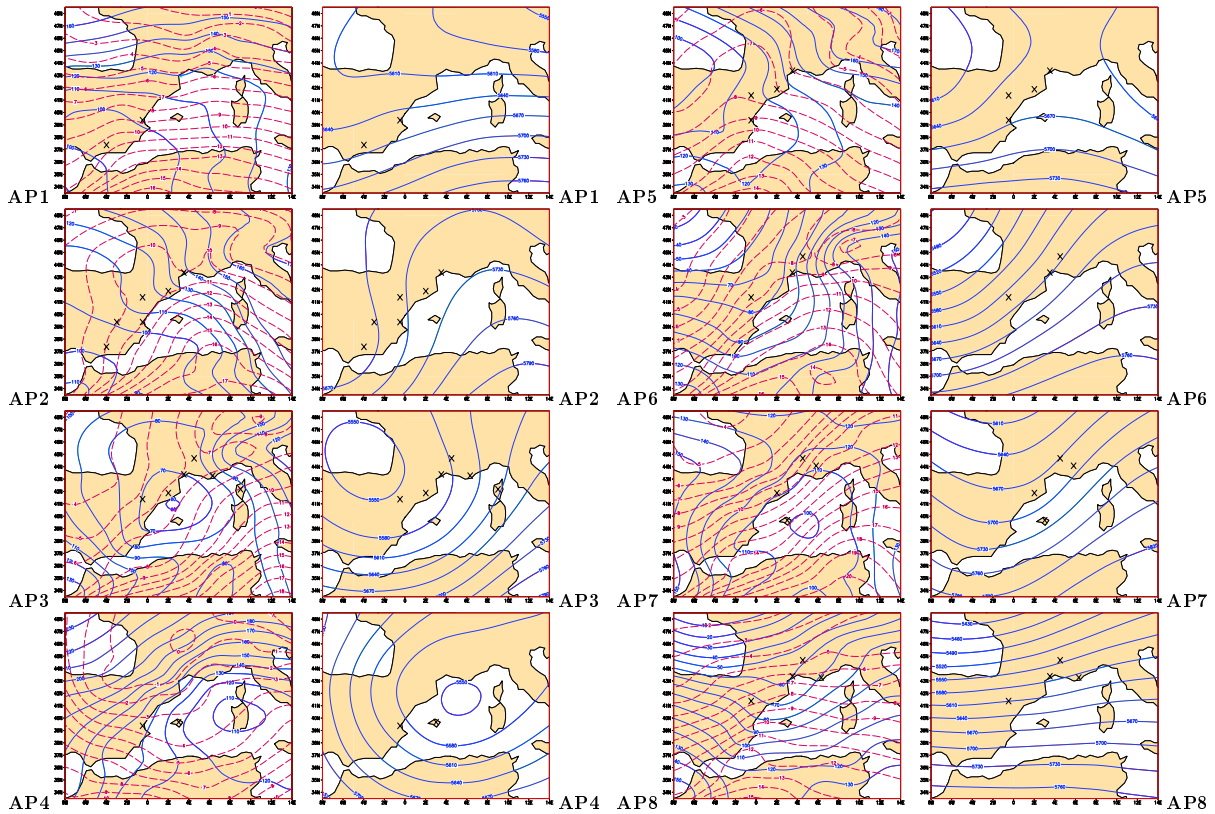
Figure 1. Averaged atmospheric fields for each AP. Panels with two fields: ϕ_{1000} (blue solid lines, 10 gpm) and T_{850} (red dashed lines, 1°C). Panels with one field: ϕ_{500} (blue solid lines, 30 gpm). Marked with a cross (X) are the regions which were usually affected by HR (more than 30% of events) for each AP.
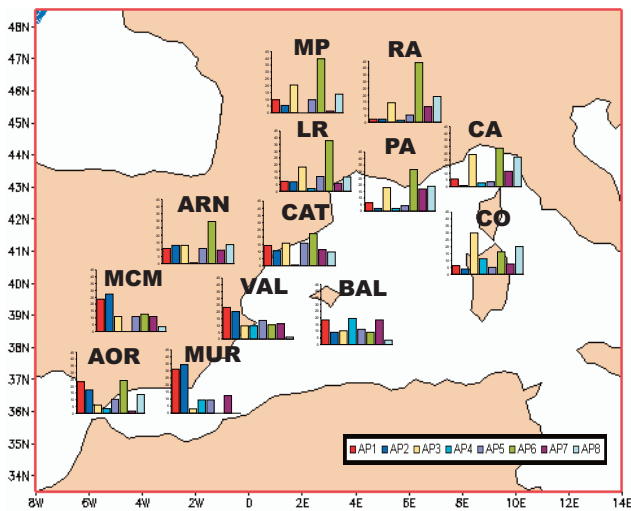
Figure 2. AP distribution (in percentage, with the y-axis scaled up to 45%) for each region.

Table 1. Percentage of HR events per season for each AP and for the total set of events.

AP	Spring	Summer	Autumn	Winter
AP1	23.9	17.9	32.8	25.4
AP2	34.1	11.4	45.5	9.1
AP3	45.2	21	21	12.9
AP4	3.2	19.4	38.7	38.7
AP5	7.7	9.6	44.2	38.5
AP6	17.3	9.6	44.2	28.8
AP7	10.6	40.4	42.6	6.4
AP8	16.9	12.3	44.6	26.2
TOTAL	20.8	16.5	39.2	23.5

To obtain the atmospheric configuration that induces a HR event, the classification is made for the HR event day (hereafter, DHR) and also for the previous day (hereafter, DHR-1). The atmospheric data fields that are used are the gridded analysis of geopotential at 1000 hPa and at 500 hPa and temperature at 850 hPa, (hereafter, ϕ_{1000}, ϕ_{500} and T_{850}), from the HIRLAM-INM-0.5° operational analysis, smoothed by a Cressman Filter with r_0=200 km (Cressman, 1959).

It is considered that these fields can be used as an initial approach for a general view of the dynamical mechanisms of HR generation. To represent the atmospheric configuration for a day, the 12:00 UTC analysis is selected. The area where the research is made, is centered in the Western Mediterranean, and it extends over a domain placed between 33.5° N and 48.5° N latitude, and between 8° W and 14° E longitude, which implies 1395 grid points. In order to obtain the Atmospheric Pattern classification (hereafter, AP) a Principal Component Analysis (PCA) and a Cluster Analysis (CA) are made (Yarnal, 1993). First, the high number of variables is reduced by applying a PCA (Wilks, 1995) to each of the 6 T-mode (day-by-day) correlation matrixes (3 for DHR and 3 for DHR-1). For each matrix only the most important loadings are considered, that is, those that account for at least 90% of the total variance. Therefore, 6 components for the matrixes ϕ_{1000} and T_{850} and 5 components for the ϕ_{500} ones are stored. After that, the CA is applied to the total matrix of loadings (34 loadings) of the 472 events. The CA classifies objects (events in this case) in groups whose elements are similar (in the sense of the loadings). That means that events with similar extracted loadings will be clustered together. The clustering algorithm used is the non-hierarchical k-means method (Andenberg, 1973). This algorithm minimizes the total within-cluster sum of squares (W). However, for this algorithm the number of groups (k) is unknown a priori, and it must be stated before the algorithm proceeds. So, taking into account that W decreases as k increases, in the present study the optimum number of groups is selected when the decrease in W is not significant (k ranging from 2 to 20); this occurs when eight groups are selected.

3 Results

Eight Atmospheric Patterns are obtained (hereafter AP1, AP2,..., AP8). For each AP the mean fields are calculated by averaging the atmospheric fields corresponding to the events clustered in each AP. For the results description it is important to take into account two key points. Firstly, the APs do not represent real atmospheric situations, they are an average of actual events, and secondly, the classification is made for DHR and DHR-1 together. As the patterns that correspond to both days are very similar, only the DHR patterns are shown. The following is a general description of each AP (see Fig. 1 and Table 1).

AP1 (67 events) This is characterized by a low pressure center located to the southwest of the Iberian Peninsula at 1000 hPa that induces a weak easterly flow towards the Spanish Mediterranean regions. At 500 hPa a trough extends from Central Europe to the Atlantic. At 850 hPa an intense temperature gradient with a warm advection can be noticed. The regions usually affected by HR are Valencia and Eastern Andalusia.

AP2 (44 events) At 1000 hPa an intense southeasterly Mediterranean flow, also produced by a low located to the southwest of the Iberian Peninsula, affects most of the regions. At 500 hPa a trough is situated over the west of the Iberian Peninsula. The temperature field at 850 hPa shows an intense ridge over the Mediterranean, with a warm advection over almost all the regions. All the Spanish regions and Languedoc (France), are affected by the HR events. Most of these events occur in autumn and spring.

AP3 (62 events) There is a cyclonic structure between Catalonia and the Balearic Islands at 1000 hPa, and a cut-off westwards, at 500 hPa. This structure induces cold northerly flow over the Iberian Peninsula and wet and warm southerly flow over the French regions. Almost 50% of the events occur in spring. The regions most frequently affected are Languedoc, Cote d'Azur, Corsica and Southern Rhone-Alpes, in France, and Catalonia and Aragon, in Spain.

AP4 (31 events) This pattern is the least frequent one. It shows a cyclonic structure over Sardinia with a cut-off low at 500 hPa west of the 1000 hPa cyclone. There is an intense northeasterly flow that produces a cold temperature advection. The Balearic Islands and Valencia are the regions most frequently affected by HR for this AP. Most of these events occur in winter and autumn.

AP5 (52 events) A pressure center to the west of the Iberian Peninsula, induces a warm, moist southerly flow over all the regions. At 850 hPa, a strong thermal ridge extends over the domain under consideration and at 500 hPa there is a strong difluent flow over almost all the regions. Languedoc, Catalonia, Valencia and Aragon are the regions mostly affected by HR events. The events occur mainly in winter and autumn.

AP6 (104 events) This pattern is the most frequent one. A surface low pressure center, located to the northwest of France, affects all the regions, in particular with a warm and moist southerly Mediterranean flow over the French regions and the Balearics, and with a cold westerly flow over the Iberian Peninsula. At 500 hPa the main feature is a trough. The regions affected by HR on most days are Rhone-Alpes, Aragon and specially Languedoc, with a significant 72% of days for this AP. Most of the HR days occur in autumn.

AP7 (47 events) At 1000 hPa a weak cyclonic structure over the Balearic Islands can be noticed. This circulation generates a cold temperature advection in the western side of the domain (Spain), and a warm advection in the northeastern one (French regions). At 500 hPa all the regions are under the influence of a trough, located over Spain. The temperature field shows an intense gradient. The highest frequency of events for this pattern occurs in autumn and summer. The Balearic Islands, Provence, Rhone-Alpes and Catalonia are the regions involved in most events.

AP8 (65 events) This shows almost zonal circulations at 1000 hPa and 500 hPa fields. It is probably characterized by the passage of cold fronts from Atlantic towards the Mediterranean. A weak coastal trough is reflected at 1000 hPa.

The regions mostly affected by HR are Rhone-Alpes, Cote d'Azur, Languedoc and Aragon. A large percentage of these events take place in autumn.

## 4	Discussion

Depending on the 1000 hPa flow (as derived from the 1000 hPa geopotential pattern) and on the regions mostly affected by HR, the eight APs obtained above can be grouped in three main types. A different group of regions is affected by HR when a different variety of APs is shown.

The first AP type groups AP1, AP2 and AP5. In all of these patterns a low pressure centre is located to the SW or W of the Iberian Peninsula, outside the Mediterranean, and an easterly flow blows in the Western Mediterranean, carrying wet Mediterranean air against the eastern flanks of the Iberian Peninsula. These regions (Eastern Andalusia, Valencia, Catalonia) are the most frequently affected by HR when any AP of this group is presented. Within this type, when the low centre is located more to the south (AP1), the southern regions are more affected, and the contrary occurs when the low centre is located more to the north (AP5). AP2 is an intermediate situation.

The second AP type groups AP6 and AP8. For this group the main low centre is a large depression located far away, in the Atlantic, to the north (AP8) or to the northwest (AP6) of the Iberian Peninsula. The corresponding low-level flow within the Mediterranean is southerly, even southeasterly (AP6), or southwesterly, giving a wet Mediterranean air inflow largely in southern France, where HR can occur. Aragon (probably the Central Pyrenees) can also be affected by HR, probably due to Atlantic air feeding.

The third AP type groups AP3, AP4 and AP7. This group is characterised by the presence of a clear low pressure centre within the Mediterranean basin that encourages the existence of wet Mediterranean air flow or a marked convergence. The exact location of the Mediterranean low determines where these meteorological factors are presented. The French regions, northeastern Spain and the islands (the Balearics and Corsica) are the areas mostly affected by HR.

From another point of view, for every HR affected region, the relative frequency of each AP can be checked. Doing this (see Fig. 2), we find that when HR affects the inland French regions, the AP present is mainly AP6, followed by AP3 and AP8. When HR occurs in Catalonia or Aragon, the associated AP is also mainly AP6. When HR affects the SE Spanish regions (Eastern Andalusia, Valencia, Murcia and Castilla la Mancha), the most frequent APs are AP1 and AP2. When the area affected by HR is the Balearic Islands, the most frequent AP is AP4, followed by AP1 and AP7. This is congruent with the results obtained by Lana et al. (2007). In general, the results concerning the Spanish Mediterranean regions are consistent with those obtained by Romero et al.

(1999). Finally, when HR affects Corsica, the associated AP is mainly AP3.

## 5	Conclusions

Eight atmospheric patterns related to heavy rain events in the Spanish and French Mediterranean regions have been obtained. These atmospheric patterns have been derived from gridded analyses of geopotential at 1000 hPa and 500 hPa and temperature at 850 hPa. Each atmospheric pattern has been described and the corresponding regions most probably affected by heavy rain have been identified. Results show a good agreement between atmospheric fields and affected regions. Therefore, despite the fact that the atmospheric patterns represent averaged fields, they could be used as a valuable tool to forecast heavy rain events in such regions.

References

Andenberg, M. R.: Cluster analysis for applications, Academic Press, New York, 359 pp., 1973.

Campins, J., Jansà, A., and Genovés, A.: Heavy rain and strong wind events and cyclones in the Balearics, Adv. Geosci., 7, 73–77, 2006,
http://www.adv-geosci.net/7/73/2006/.

Cressman, G. P.: An operational objective analysis system, Mon. Weather Rev., 87, 367–374, 1959.

Esteban, P., Jones, P. D., Martín-Vide, J., and Mases, M.: Atmospheric circulation patterns related to heavy snowfall days in Andorra, Pyrenees, Int. J. Climatol., 25, 319–329, 2005.

Houssos, E. and Bartzokas, A.: Extreme precipitations events in NW Greece, Adv. Geosci., 7, 91–96, 2006,
http://www.adv-geosci.net/7/91/2006/.

Jansà, A., Genovés, A., Picornell, M. A., Campins, J., Riosalido, R., and Carretero, O.: Western Mediterranean cyclones and heavy rain. Part 2: Statistical approach, Meteorol. Appl. 8, 43–56, 2001.

Lana, A., Campins, J., Genovés, A., and Jansà, A.: Atmospheric patterns for heavy rain events in the Balearic Islands, Adv. Geosci., 12, 27–32, 2007,
http://www.adv-geosci.net/12/27/2007/.

Plaut, G., Schuepbach, E., and Doctor, M.: Heavy precipitation events over a few Alpine sub-regions and the links with large-scale circulations, 1971–1995, Climate Res., 17, 285–302, 2001.

Romero, R., Sumner, G., Ramis, C., and Genovés, A.: A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean area, Int. J. Climatol., 19, 765–785, 1999.

Trigo, R. M. and DaCamara, C. C.: Circulation weather types and their influence on the precipitation regime in Portugal, Int. J. Climatol., 20, 1559–1581, 2000.

Wilks, D.: Statistical methods in the atmospheric sciences, Academic Press, New York, 1995.

Yarnal, B.: Synoptic climatology in environmental analysis, Belhaven Press, London, 1993.