Atmospheric patterns associated with hailstorm days in the Ebro Valley (Spain)

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I. INTRODUCTION

The Central Ebro Valley, in the Northeast of Spain (Fig. 1), is one of the regions in Europe with the highest number of summer convective storms that cause intense and heavy rain and hail precipitation (Font, 1983). The zone lies between parallels 39^o 51' and 42^o 55' of latitude north, and meridians 2^o 06' of longitude west and 0^o 44'of longitude east. The Group for Atmospheric Physics (GAP) at the University of León (ULE), Spain, has carried out a series of research projects in this area over the last ten years. The main aim of these projects is the study of severe convective events that affect the Central Ebro Valley, causing heavy rain and hail precipitation.

The GAP has investigated the nature of these convective events, in order to improve the forecasting and nowcasting of the hailstorms. García-Ortega et al. (2006) established the microphysical characteristics of a severe hailstorm in the study area. Different prediction techniques, using radiosonde data (López et al., 2007) and nowcasting, using meteorological radar (López et al., 2009) has been used. Numerical simulations via the Mesoscale Model MM5 have been carried out in order to analyse different study cases (Tudurí et al., 2003; García-Ortega et al., 2007).

The GAP is currently engaged in research work to develop a forecast model for hail precipitation risk, based on the identification of meteorological situations that may lead to convective events and cause hailstorms in the Ebro Valley. The main objective of the present study is to obtain an atmospheric pattern classification of a set of hailstorm days (hereafter, HD) that affected the Central Ebro Valley between 2001 and 2008.

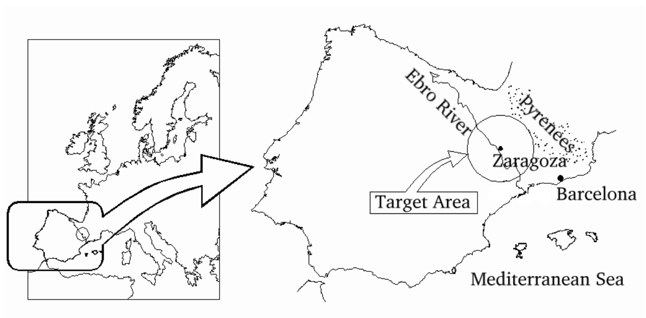

FIG. 1: Target area: the region of Aragón (Northeast of Spain). The circle comprises the area covered by the C-band radar (about 140 km of radius)

II. DATA AND METHODOLOGY

The database cointains 260 HD from 2001 to 2008. The HD data comes from the C-band radar database of GAP and a network of voluntary observers. The radar is deployed 10 km to the SW of the city of Zaragoza with a range of 140 km in radius (Fig. 1). The radar provides information on the horizontal and vertical structure of the storms with a spatial resolution of 1 km and a temporal resolution of 4 min.

Gridded reanalysis data from the National Centers for Environmental Prediction (NCEP) are used, with a $2.5^o \times 2.5^o$ latitude-longitude resolution. The area selected comprises the domain from 30^o N to 50^o N and from 40^o W to 10^o E. The selection of a group of independent variables representative of the state of the atmosphere will supply a synoptic meteorological categorization of the atmospheric characteristic of HD. The initial ensemble of atmospheric fields consists of the 850 and 500 hPa geopotential height and temperature (ϕ_{850}, ϕ_{500}, T_{850}, T_{500}) and the 850 hPa relative humidity (hr_{850}). In order to obtain the atmospheric pattern classification, a Principal Component Analysis (PCA) and a Cluster Analysis (CA) were carried out (Yarnal, 1993).

The PCA was applied to extract the most important components of the initial variables and to explore the joint space and time variations in the data set. The PCA in T-mode (day-by-day) has been used to isolate groups of time steps with similar patterns. Only the most important loadings -those that account for at least 90% of the total variance- were considered for each parameter. As a result, 6 components were stored for ϕ_{850}, 4 components for ϕ_{500}, 3 for T_{850}, 8 for T_{500} and 14 components for hr_{850} were selected. The CA was applied to the total matrix of 35 loadings of the 260 events.

The CA classifies events in groups whose loadings are similar. Therefore, events with similar extracted loadings will be clustered. The non-hierarchical k-means method (Andenberg, 1973) has been used. This algorithm minimizes the total within-cluster sum of squares. However, for this algorithm the number of groups (k) must be stated before the algorithm proceeds. In order to select the number k we have analysed the results obtained via PCA, other hierarchical methods such as Ward's method, and appliying the Elbow criterion to the results obtained with CA.

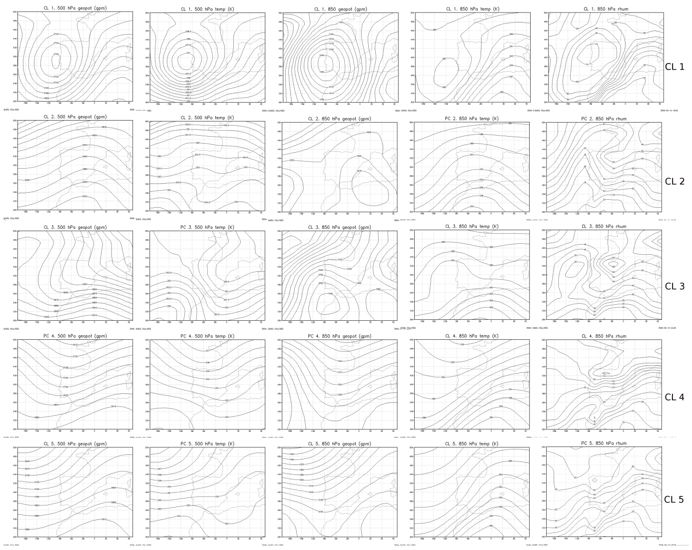

FIG. 2: Atmospheric patterns based on CA. Clusters 1 to 5 labeled as CL 1, CL 2, ..., CL 5 are in rows. The atmospheric fields are in columns: ϕ_{500} (gpm), T_{500} (K), ϕ_{850} (gpm), T_{850} (K), rh_{850} (%).

III. RESULTS AND CONCLUSIONS

Five atmospheric patterns were obtained (Fig. 2). The clusters are numbered following the order obtained on the k-mean output. In order to make the physical interpretation of the results, we have calculated the mean fields, for each cluster element (CL), averaging the atmospheric fields corresponding to the events grouped in each element. Obviously, each CL is not a real atmospheric pattern, but an average of real ones.

The CL 4 and CL 5 are the atmospheric patterns with the highest number of days (90 and 98 respectively). These two CL, together with CL 2 (39 days) configure a unique dynamic structure. CLs 2, 5 and 4 show a sequence corresponding to the arrival of a trough, ϕ_{500}, from the Atlantic Ocean with an associated cold advection (Fig. 2). From CL 2 to CL 4 the isotherm over the study area develops from $262.5\ K$ to $259.5\ K$. At $850\ hPa$ the entry of a trough is also noted, whose development is strongly influenced, particularly in CL 2, by a high-pressure center situated over Algeria. The hr_{850} reveals a center with maximum values in the NW and N of Spain.

CL 1 (17 days): At 500 hPa, the ϕ_{500} is characterized by a cut-off low centered over the west of Portugal and an associated low-temperature center (T_{500}). A similar structure can be observed at 850 hPa (ϕ_{850}). At low levels, the south-easterly flow over the northeast of Spain favours the entrance of warm and humid air over the study area. This is an important factor for the generation of heavy hailstorm events. The entrance of the cut-off low will favour the upward motion. The situations associated with this CL normally occur during the months of May and September, in which the formation of the low in the W of the Peninsula and the associated low temperatures are a characteristic event around this period.

CL 3 (16 days): At 500 hPa, the ϕ_{500} shows a through tilted to the southwest over the Iberian Peninsula generating a situation of instability. The cold air at 500 hPa comes from the interior of the European continent. At 850 hPa, there is a trough affected by a low-pressure center situated over the Gulf of Cádiz. The displacement of this low towards the NE favours the entrance of warm and humid air from the Mediterranean Sea. This structure is not too frequent but is related with strong rainfalls.

The results obtained reveal 5 clusters corresponding to three types of differentiated atmospheric patterns. CL 1 is characterized by the presence of a deep low-pressure center situated to the W of Portugal at both low and medium levels. CL 3 reveals a trough at 500 hPa tilted to the NW and a trough at 850 hPa influenced by a low-pressure area situated over Morocco. CL 2, 5 and 4 correspond to 72.3% of the cases studied. At 500 hPa the entrance of a trough is observed moving eastwards with a strong cold air advection.

IV. ACKNOWLEDGMENTS

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