Proceedings of ERAD (2004): 464–468 © Copernicus GmbH 2004

ERAD 2004

Convective storm initiation in central Catalonia

R. Pascual[1], **A. Callado**[1], **and M. Berenguer**[2]

[1]Instituto Nacional de Meteorología, Barcelona, Spain
[2]Grup de Recerca Aplicada en Hidrometeorologia, Universitat Politècnica de Catalunya, Barcelona, Spain

Abstract. Spanish National Weather Service (INM) 1-km resolution radar reflectivity data at 10 min intervals have been examined to determine location and timing of storm initiation occurring over central Catalonia during June, July, August and September 2003. For each day, regions of convective initiation are identified using two methods: one indirect determining diurnal relative frequencies of radar reflectivity and another direct identifying and tracking the convective cells with and operational automated algorithm.

High resolution Polar Satellite imagery, surface pressure fields and surface data are also examined to identify stratiform cloudiness and/or cumulus convection previous to the radar signal and to infer the existence of boundary layer convergence lines/zones (Boundaries).

Boundaries generated under some specific synoptic and mesoscale patterns and convergence zones tied to the orography are recognized in Catalonia as the favorite places to develop shallow or deep convection. As a result of previous subjective analysis 4 different kinds of planetary boundary layer convergence zones and processes have been recognized in the domain: Sea-breeze/coastal ranges interaction, Catalonian-Balearic convergence zone, Tramontane negative vortex/land-breeze interaction and prefrontal troughs. This paper presents the results of the statistical objective approach that has been carried out to validate these previous conclusions.

Since it is not easy to identify clear air boundaries, the knowledge of the preferred areas and synoptic and mesoscale conditions for storm initiation over Catalonia has potential benefits on convective storm nowcasting and short range forecasting.

1 Introduction

Forecasting of convection initiation is one of the main current challenges in operational nowcasting tasks in the Spanish National Weather Service. Knowledge of areas where convection develops most frequently (hot spots) is a previous step to obtain accurate nowcasts.

Correspondence to: R. Pascual
(ramonp.bar@inm.es)

Convection climatologies in Catalonia have been obtained using lightning data (Terradelles, 1997) and infrared satellite imagery (Pascual, 1999). Both studies have shown the importance of the orographic component and the diurnal cycle in triggering convection as well as the role of the Mediterranean Sea as a heat source, especially in autumn, increasing notably the convective activity over it and over the coast.

The use of radar data to analyze convection initiation has lead to associate the development of a new cell to the presence of a planetary boundary layer convergence zone (Wilson et al., 1986). Previous studies carried out in Catalonia (Pascual et al., 2002; Callado et al., 2002) have analyzed subjectively the origin of convection identified in radar data with low levels convergence zones.

The goal of this study is to objectively analyze the convective activity during the summer of 2003 and to relate it with convergence areas associated to terrain characteristics and/or to the interaction between different flows at low levels.

2 Data and methodology

Main characteristics of the Doppler radar used in operational tasks and in this study are given in Sect. 2.1. The other tools used and their role in the identification and characterization of convective structures area presented in Sect. 2.2.

2.1 Doppler radar

The Spanish National Weather Service (INM) has a network of 15 C-band Doppler radars covering almost all the Iberian Peninsula and some maritime areas. The radar of the INM installed in Catalonia is located about 20 km South-West from Barcelona, and at 654 m above mean sea level (MSL). Table 1 summarizes the principal characteristics of this radar.

Table 1. Main characteristics of INM Doppler radar used in this study.

Wavelength (cm)	5.4 (C-band)
Resolution (km^2)	2×2
Range (km)	Normal:240
Exploration Interval (min.)	10
Peak Power (kW)	250
Beamwidth (deg.)	0.9°
Pulselenght (m)	Normal: 600

2.2 Other tools of interest

Polar 1.1-km satellite imagery from NOAA-16 and 17 (channels 2 and 6), has been used to characterize the cloudiness field and briefly describe the context where convection develops. Convection may be isolated or widespread and can develop on clear skies or embedded in a wide stratiform and sometimes multilevel cloud cover.

INM-High Resolution Limited Area Model (HIRLAM) outputs have been analyzed to classified each day in a synoptic typical regime. Geopotential height and temperature at 500-hPa and sea level pressure have been the fields selected for this purpose.

Data from the INM lightning network has also been used to filter the days to be studied.

2.3 Methodology

Radar reflectivity data at 10 min intervals have been examined to determine location and time of storm initiation occurring over central Catalonia from June to September 2003.

2.3.1 Database generation

An initial database of 122 days (17568 polar volumes of radar reflectivity) is theoretically available. As a first step days in which no cloud to ground electrical discharge has been detected by the INM lightning network in a circle of 300 km diameter centered in the radar have been rejected. Days with a few number of discharges (less than 10) have been carefully analyzed and they have only accepted only if discharges occurred in a range of less than 120 km. Although it is possible that some convective cells don't produce discharges it is unlikely that these cells could be identified by the detection algorithm used later. The result of this filtering is a set of 82 days (of a total of 122).

The second step consisted on correcting these original raw polar volumes: ground clutter identification and substitution, correction of orography screening effects and the general signal decay due to rain over the radome recovering (Sempere-Torres et al., 2003). These corrections are fundamental because detection of 2D convective structures is very sensitive to reflectivity horizontal gradients and to local reflectivity value.

Finally, radar scans without any meteorological echo have been removed previously to run the convective cells identification and tracking. One of the main difficulties has been to discriminate the ground clutter echoes associated to anomalous propagation conditions from precipitation echoes, present sometimes simultaneously in convective environments. An automated method combined with the examination of the loops for the 82 days has removed some of these "bad" volumes resulting finally in a enough good set of radar images but, as has been showed later, with still some anaprop echoes.

Finally, a subset of 15 days with a significant lack of PPI0 has been removed of the database. Finally 67 days (with over 90% of radar scans available), have been analyzed.

2.3.2 Convective cells origin identification

Two methods have been carried out to infer some characteristics of convection initiation in a square of 240 km side centered in the radar location: One indirect determining diurnal relative frequencies of radar reflectivity (MacKeen et al., 2001) and another direct identifying and tracking convective cells with an objective algorithm based on the identification algorithm developed by Steiner et al. (1995), and operational on the IMM-McIDAS system (Martín, 2001).

Relative frequencies of radar reflectivity have been calculated for 00:00, 03:00, 06:00, 12:00, 15:00, 18:00 and 21:00 UTC and for 4 reflectivity thresholds: 30 dBZ, 35 dBZ, 40 dBZ and 45 dBZ. The density has been calculated over a 10 km spacing grid. To filter some spurious echoes a minimum area criterion (8 km^2) has been imposed. Corresponding contours represented over digital elevation data have been prepared to examine diurnal and monthly evolution of the reflectivity field and to infer some key elements of convection initiation.

On the other hand, objective identification software (YRADAR) has been ran over the selected PPI0 of the 67 days generating a set of files containing information about geographical coordinates, time, dimension, and maximum and mean reflectivity for each 2D potentially convective structure identified. Tracking allowed identifying a cell as new when it is not linked to any previous structure (Wilson et al., 1986). The main characteristics of the objective identification software are that a pixel is identified as convective if: $Z \geq 45$ dBZ or $Z \geq 40$ dBZ and this pixel is a local maximum (horizontal gradient criterion) or the pixel is close enough to a convective pixel (neighborhood criterion).

A total of 5560 2D convective structures have been identified in the radar complete domain (480 diameter; 180 956 km^2) and 2579 convective structures in the 240 km side square (57 600 km^2). The presence of distance related factors affecting the radar measurements (beam elevation, pulse volume increase, etc.) recommends to limit the convection initiation analysis to 240×240 km^2 square.

The representation of this information over an orographic basis for each day, for the days all together and for 6 groups of days according to the synoptic environment has been the main tool to infer some characteristics of the convection initiation at central Catalonia at 2003 summer season.

3 Orography and relevant summer climatology

Catalonia is located at the North-Eastern part of Spain and limited by the Mediterranean Sea (by the East and South), the Pyrenees range at the North, and by the Ebro river valley at the West. The Pyrenees, reaching 3000 m, and the two ranges extending North-East to South-West and located parallel to the coast, reaching more than 800 m at only 10 km from the coast, are the more relevant topographic elements. These NE-SW oriented ranges block the maritime wet wind associated to heavy rainfall events that occur at the eastern side of these mountain ranges. At the western side total annual precipitation is not large and the phenomenology associated with summer convection is clearly different: hail or large hail and strong winds are not rare.

There are two main fluvial systems that determine the inland penetration of maritime air masses and the presence of convergence areas: the rivers that flow from the eastern Pyrenees or from the coastal ranges, flowing to the East directly to the sea and the rivers that flow southward from the central and western Pyrenees, to the Ebro river.

The summer climatology is characterized in general by a sparse precipitation and high temperatures, but this pattern is very influenced by the complex orography. Weak or moderate sea and land breezes are present most of summer days near the coastline and mountain breezes are also present especially in the main ranges.

4 2003 summer season characteristics

This summer was characterized in western Europe by a nearly persistent anticyclonic blocking, with a ridge at 850, 700 and 500-hPa, oriented S-N, SE-NW or SW-NE and centered over the Iberian Peninsula, France or Central Europe, in a position somewhat more eastern than normal. Temperatures at 850-hPa were extremely high over Catalonia (mean value for the 4 months: 16.9°C, but especially from June to, August, with a mean value of 18.4°C and a maximum value of 23°C). At synoptic scale the atmosphere was very stable, especially the first three months (the mean lifted index from June to August was 1°C). Surface temperatures were extremely high and precipitation sparse in general.

Synoptic patterns have been categorized into eight types by examining upper levels and surface analysis for the data set: dynamic anticyclone (17 days), dynamic anticyclone with thermal low at the Iberian Peninsula (23 days), thermal low at the Iberian Peninsula and a synoptic-scale or mesoscale short wave trough at 500-hPa (34 days), synoptic-scale short-wave trough at all levels (2 days), northerly flow (1 day), southwesterly flow (2 days), anticyclonic easterly flow (1 day) and very weak sea level pressure gradient (2 days). This distribution agrees with the annual normal distribution with the natural bias related to the fact that this set of days has been previously selected from the complete series.

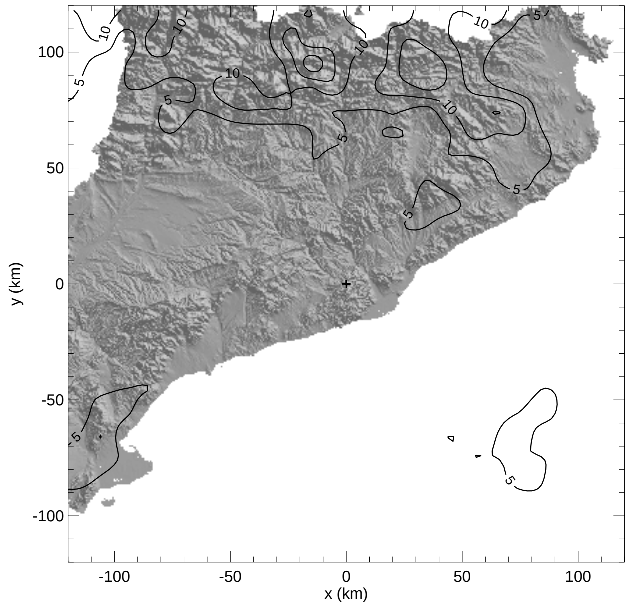

Fig. 1. Relative frequency (%) of radar reflectivity echo values equal or greater than 35 dBZ at 15:00 UTC. The contour interval is 5 %.

5 Results and discussion

The main observed elements resulting from relative frequency maps and new cells plotting examination are presented here. Some possible planetary boundary layer convergence zones and mechanisms associated to convection initiation are also suggested.

5.1 Density maps

Examination of the total maps (00:00 to 21:00) for the four thresholds (30 to 45 dBZ) show some interesting aspects. First of all it is important to remark that, in spite of the precautions taken, ground clutter echoes associated to anaprop conditions still appear.

The main elements to be highlighted are:

– Higher relative frequencies for all the analyzed reflectivity thresholds appear from 09:00 to 18:00 UTC related to the diurnal cycle. Highest values are around 15% to 20% at 15:00 UTC in very high convective areas in eastern Pyrenees. This fact can be related to the proximity of Mediterrean Sea and while mountain breezes can play the role of triggering convection, sea breeze can supply additional moisture but this is a hypothesis that should be further investigated (Fig. 1).

– Some local maxima with relative frequencies over 5% for 45 dBZ can only be found between 15:00 and

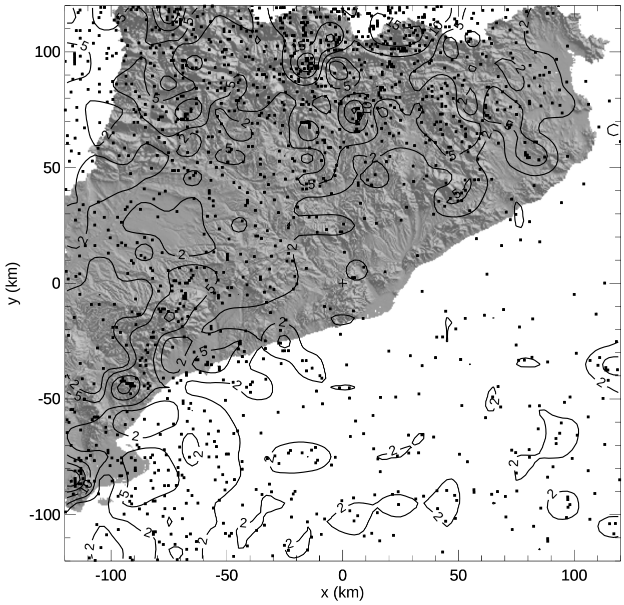

Fig. 2. 2D convective structure initiation locations for the 67 days set without the 8 more convective days. The contours represent new cells number in a grid of 10 km spacing. The contour interval is 5 new cells.

18:00 UTC, but frequencies over 5% for 40 dBZ are present between 06:00 UTC and 18:00 UTC in some mountainous areas in the northern half of Catalonia.

– There is a few number of areas offshore, between Barcelona and the Ebro Delta, 100 km to the South, with relative frequencies over 5% for 35 dBZ, at 06 UTC and 09 UTC respectively. Callado et al. (2002), suggested that these small convective areas arise from interaction between nocturnal land breeze and a weak easterly synoptic flow or in the offshore land breezes deceleration convergence zone.

– Higher relative frequencies for all thresholds appear in mountainous terrain, especially in the Pyrenees range. This is clear in regimes with weak synoptic forcing and even with general convection inhibition conditions. The role of main ranges as elevated heat sources (Barry, 1981) seems to be crucial these days.

– Frequencies over 5% for 35 dBZ are present first (12:00 UTC) in an area of eastern Pyrenees (Freser river, Ter river, Llobregat river and Segre river headwaters) including peaks higher than 2800 m. Between 12:00 and 15:00 UTC 5% contours extend to southeast (along Transversal Range), to the South (covering the southern foothills of the Pyrenees) and to the West (covering western catalan Pyrenees). At 18:00 UTC 5% contours are limited to Pyrenees, Montseny mountains, and some other sparse and small areas.

The examination of the density maps for every month also show another interesting element:

There is a seasonal bias for frequency values over the sea. Higher values appear in August and September, as Terradelles (1997) showed. This bias is related to the seasonal trend of land-sea temperature gradient and also to a higher frequency of synoptic regimes with significant forcing. Convection under strong or moderate synoptic forcing can be initiate over flat terrain, as well as over the sea. In this case convection triggering in the intersection between two or more storm outflows is frequent.

5.2 2D convective structures initiation location and timing

The map containing the plot of new cells objectively identified during the four analyzed months shows a scattered and apparently random distribution, with cells developed over land and over the sea all over the radar domain.

In order to improve this map, the most convective 8 days (12% of the total time) with more than 150 new cells identified over the complete radar domain (which represents the 33% of the total). This bias in the daily distribution of new identified cells is a consequence of the synoptic regime present these days, thermal low at Iberian Peninsula with a short wave trough at 500-hPa, and that September is the most convective month (6 days of the most convective days occurred in September). After removing these days a more clear distribution of hot spots has been obtained.

This analysis shows again (Fig. 2) the influence of the orographic component in the convection initiation geographical distribution. Maxima for the 67 days analyzed are concentrated in 3 zones of the Eastern Pyrenees, extending SE with secondary maxima, and 1 zone in Western Pyrenees. A secondary maximum in the southern third of the coastal range (Montsant-Prades mountains) is also clearly identified. Finally, it is possible to identify areas with a very low frequency of new cells development: some areas of the northern half of the coastal region and the eastern edge of the Lleida Plain.

Stratifying the set of 67 days according to synoptic regime it is possible suggest some relation with the convection initiation mechanisms:

– The 20 days under dynamic anticyclone and thermal low at Iberian Peninsula comprises events where convection development is limited mostly to mountainous terrain (especially Pyrenees and Montsant-Prades mountains as well as other sectors of the coastal ranges).

– The 31 days under thermal low at the Iberian Peninsula and a short wave trough at 500-hPa comprises events where convection development is widespread although terrain-induced component still plays a modulating role.

– The 17 days under dynamic anticyclone comprise events where convection development is also limited to mountainous terrain but the number of cells developed is notably lower than in case of presence of a well defined heat low.

– The rest of the regime types has a number too low of cases to draw any general conclusions. However, it is interesting to notice the distribution of new cells of the ninth September, when synoptic regime was characterized by northerly flow. This type of regime, not frequent in summer, created a recurrent planetary boundary layer convergence zone between Catalonia and Balearic Islands (Pascual et al., 2002), where it is usual, as in this case, the development of convection.

Acknowledgement. Thanks are due to the Spanish Instituto Nacional de Meteorología for providing data and support.

References

Barry, R. G.: Mountain weather and climate, New York: Methuen, 1981.

Callado, A. and Pascual, R.: Storms in front of the mouth rivers in north-eastern coast of the Iberian Peninsula, 4th Plinius Conference on Mediterranean Storms, Pollentia (Spain), 2–4 October 2002.

MacKeen, P. L., Howard, K. W., and Schultz, D.: Initiation and evolution of summertime storms in central Arizona, 30th International Conference on Radar Meteorology. Munich (Germany), 19–24 July 2001.

Pascual, R.: Convección estival en Cataluña. Un análisis mediante imágenes IR de Meteosat, IV Simposio Nacional de Predicción, Instituto Nacional de Meteorologia, Madrid (Spain), 15–19 April 1996, 1999.

Pascual, R. and Callado, A.: Mesoanalysis of recurrent convergence zones in north-eastern Iberian Peninsula, Second European Conference on Radar Meteorology ERAD, Delft (Holland), 18–23 November 2002.

Martín, F.: Identificación objetiva de estructuras convectivas a partir de los datos radar del PPI/CAPPI bajo en MCIDAS, V Simposio Nacional de Predicción, Instituto Nacional de Meteorologia, Madrid (Spain), 20–23 November 2001.

Sempere-Torres, D., Sanchez-Diezma, R., Berenguer, M., Pascual, R., and Zawadzki, I.: Improving radar rainfall measurement stability using mountain returns in real time, 31th Conference on Radar Meteorology, Seattle (USA), 6–12 August 2003.

Steiner, M., Houze, R. A., and Yuter, S. E.: Climatological characterization of three dimensional storm structure from operational radar and raingauge data, Journal of Applied Meteorology, 34, 1978–2007, 1995.

Terradelles, E.: Main features of the distribution of the atmospheric electric activity in Catalonia and the surrounding mediterranean area, INM/WMO International Symposium on Cyclones and Hazardous Weather in the Mediterranean, Palma de Mallorca (Spain), 14–17 April 1997.

Wilson, J. W. and Schreiber, W. E.: Initiation of convective storms at radar-observed boundary-layer convergence lines, Monthly Weather Review, 114, 2516–2536, 1986.