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2D and 3D radar analysis of the 2004-2005 hail campaigns in NE of Spain

Manuel Ceperuelo[1], María-Carmen Llasat[1], Tomeu Rigo[2]

[1] Department of Astronomy & Meteorology, University of Barcelona, Barcelona (Spain).

[2] Meteorological Service of Catalonia, Generalitat de Catalunya, Barcelona (Spain).

1 Introduction

Summer storms are very frequent in the Ebro Valley (NE of Spain), mainly in the south-western part that have an average of 32 thunderstorm days per year over an area of 25000 km^2, (Font, 1983). Frequently these storms are associated with hail in surface. Previous studies (Pascual, 2000; López, 2003) have shown that the medium size of hailstones in this area is usually less than 20mm, which is usually registered around 16:00 UTC, after the maximum irradiance value.

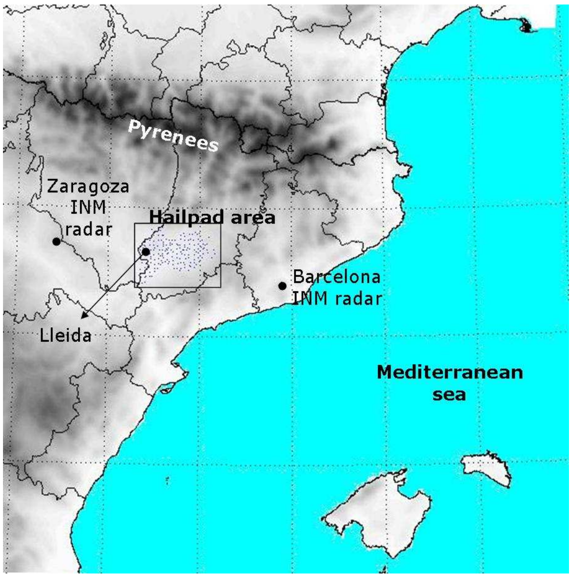

Fig. 1. Study area

A number of 814 ground hail observations corresponding to 70 hail events have been recorded in the Ebro Valley during the last two field campaigns held on 2004 and 2005 between the months of May and September. The largest recorded hailstones have had a size of 43.9mm (2004) and 39.4mm (2005). The contribution focuses on those events that have affected the LLeida region, in Catalonia (Fig. 1). Specifically, the paper deals with the characterisation of the associated convective cells as well as their tracking, with the purpose to identify their life cycle and the best parameters to distinguish between cells responsible of hail and cells without hail. To achieve this end, the hailstorm analysis tool RHAP (Rainfall events and Hailstorms Analysis Program) has been applied. The program integrates meteorological radar data, meteorological model outputs, radiosonde observations and surface observations, like hailpads.

Correspondence to: Manuel Ceperuelo.

ceperuel@am.ub.es

The present paper starts with the description of the data base and the methodology employed. Then, the analysis of 3D cells using RHAP has been done. Finally, conclusions are presented.

2 Data Base

A wide range of data has been used to study all the hail events: radar data, hailpad data and mesoscale meteorological model outputs.

2.1 Hailpads

Ground observations have been provided by the hailpad network belonging to the ADV, "Associació de Defensa dels Vegetals" (Association for the Protection of Plants) in Lleida (Fig. 1). This network is formed by 170 hailpads and its density is close to 1 hailpad per 16 km^2 and provides, among other data, values of maximum hail size, ice mass, kinetic energy and number of impacts per m^2 (Schleusener and Jenings, 1960; López, 2003). Hailpad observations have been checked with radar data.

2.2 Radar

The meteorological radar of the Spanish National Institute of Meteorology (Instituto Nacional de Meteorología, INM), placed in Zaragoza has been used (Fig. 1). It is a C-band radar with 10 minutes time step. The main radar features are shown in Table 1.

Table 1. INM radar features.

Feature	Value
Beamwidth	0.9º
Frequency	5600-5600 MHz
Pick power	250 kW
Pulse width	2 μs
PRF	250 Hz

2.3 Meteorological Model

The Mesoscale Meteorological Model MM5 has been used in order to obtain some radar parameters which depends on the environmental conditions and the wind fields at four different levels (925, 850, 700 and 500 hPa) to carry out the 3D cells tracking of the hail events. The initial and boundary conditions have been obtained from the FNL/NCEP analyses (1º latitude x 1º longitude, every 6 h) and observational data. The simulations have been designed for three domains connected with two way nesting and having 72, 24, 8 km horizontal grid resolution and vertical resolution of 23 levels. Full physics have been used and the Betts-Miller scheme (Betts and Miller, 1993) has been applied to parameterise convection for the first domain, the Kain-Fritsch scheme (Kain and Fritsch, 1993) for the second domain and the Grell scheme for the third domain (Grell et al., 1994).

3 Methodology

All the previous data have been integrated with RHAP software (Ceperuelo at al., 2006). This software has been built on the basis of the improvement of different techniques for the specific region. The 3D cells identification and characterization combines the adaptation and improvement of the SCIT algorithms (Johnson et al., 1998; Rigo and Llasat, 2004) adding more radar parameters. The hail detection algorithm (Witt et al., 1998) has been adapted for the region of Lleida obtaining the empirical relationship between warning threshold and melting level and the severe hail probability.

The tracking algorithm is based on the TITAN technique (Dixon and Wiener, 1993) but the RHAP algorithm uses the mean wind grid point nearest to the cell centroide to extrapolate the current cell position to the previous position. The mean wind has been obtained from 925, 850, 700 and 500 hPa levels. After the position extrapolation, the cell in the previous radar image that satisfies the TITAN condition (the closest and the most similar cell) is searched in order to assign it as a tracked cell.

RHAP also enables us to identify, characterise and track the precipitation system. The classification of precipitation systems (Ceperuelo et al., 2006) is made on the basis of the proposal made by Rigo and Llasat (2004), where the percentage of convective and stratiform precipitation, the horizontal size and the duration of the system have been considered. The classification includes: mesoscale convective system (MCS), isolated convection (ISO), multicellular (MUL), convective precipitation embedded in stratiform precipitation (EST-EMB) and stratiform precipitation (EST).

Once each cell has been identified the next parameters have been analysed in order to select the best discriminating parameters: VIL “Vertical Integrated Liquid” (Greene and Clark, 1972), VILD “VIL density” (Amburn and Wolf, 1997), WP “Waldvogel Parameter” and HP “Hail Probability” (Waldvogel et al., 1979), SHP “Severe Hail Probability” (Witt et al., 1998), MEHS “Maximum Expected Hail Size” (Witt et al., 1998), kinetic energy flux (Waldvogel et al., 1978 and Witt et al., 1998) , ECHOTOPS of 20, 30 and 40 dBZ, parameters associated with environmental conditions (melting and -20ºC levels for the case of WP and SHP), parameters associated with the shape of the cells (volume, axis,…) and the associated precipitation system.

Finally, focusing on the Lleida’s hailpad area, taking into account the available data base and the necessity of having hail reports in order to discriminate hail cells from no-hail cells, 17 hail events have been analysed. Probability density functions and the best thresholds have been obtained for each radar parameter, using contingency tables and scores indexes.

4 3D cells analysis

A total of 209 no-hail cells and 56 hail cells have been identified, characterised and tracked from the 17 selected hail events. Results show that hail cells have a displacement longer than no-hail cells (Fig. 2), probably due to a major organization of the associated precipitation system in the first case. This conclusion has been corroborated by the individual analysis of each associated precipitation system, which shows than the higher the organisation the higher the hail probability (Table 2). In case of the 3D cells movement direction, the mean value is similar for both cases, 15-21º (WSW-ENE), nonetheless hail cells have an important SE-NW component of cells direction.

Table 2. Precipitation systems associated to hail and no hail observations (obs.): instants and Global and individual percentage in brackets.

Precipitation system	Hail obs.	No hail obs.
Multicellular system	39 (14%, 65%)	21 (8%, 35%)
Isolated Convection	43 (16%, 29%)	104 (39%, 71%)
EMB-EST	19 (7%, 33%)	38 (14%, 67%)
No identified	1 (0%, 20%)	4 (0%, 80%)

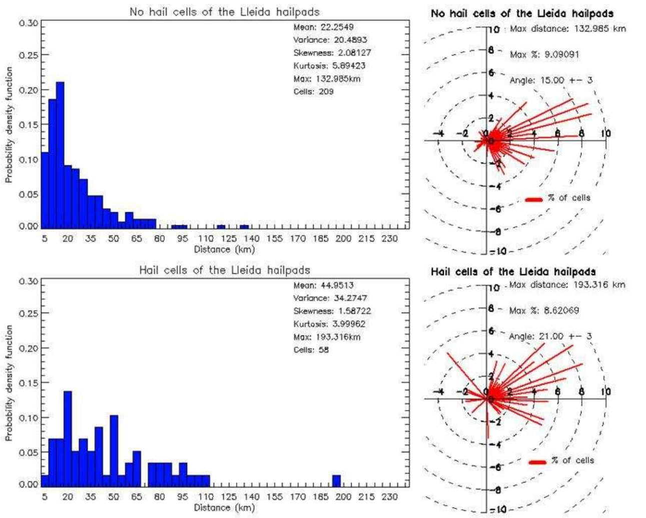

Fig. 2. Histogram of movement distances and directions of no-hail and hail cells of the Lleida's hailpad area.

The evaluation of the radar parameters has been done in order to obtain the best parameter to identify a hail or no-hail cell. For this purpose, contingency tables and the score indexes have been built (Billet et al., 1997; Brier, 1950; Donaldson et al., 1975). Results can be summarised in Table 3, where some results are shown.

Table 3. Higher critical success index (CSI) and corresponding radar parameter to identify hail and no hail cells for some radar parameters.

Radar parameter	Maximum CSI	Value
Zmax	0.3195	52.0 dBz
VIL (grid method)	0.2803	8.0 kg/m^2
VIL (cell method)	0.2695	12.0 kg/m^2
VIL (Zmax method)	0.3012	14.0 kg/m^2
VILD (cell)	0.3280	2.0 g/m^3
VILD (Zmax)	0.2703	1.75 g/m^3
WP	0.3405	3.0 km
SHP (hail>10mm)	0.3805	30.0 %

As this table shows, the best parameter to identify hail in surface is the WP, but improved by the introduction of the exponential function showed in equation (1) to model the hail probability, PH (Fig. 3).

$$PH(\%) = 23.02 \cdot e^{0.184 \cdot WP} - 11.98 \qquad (1)$$

If only hail larger than 10mm is considered, an adapted version of SHP has been shown as the best parameter to identify it. This adapted version has been obtained for the Ebro Valley region on the basis of 10 severe hail events. Then, the Warning Threshold (WT) could be calculated following equation (2), while SHP could be modelled with a logarithmical function (3) (Fig. 4).

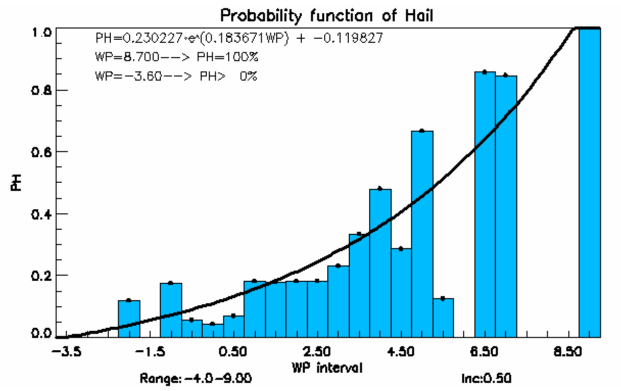

Fig. 3. Probability function of hail for WP in Lleida's hailpad area.

$$WT = 18.1 \cdot H_0 - 35.7 \qquad (2)$$

$$PH(\%) = 30.78 \cdot \ln\left(\frac{SHI}{WT}\right) + 39.35 \qquad (3)$$

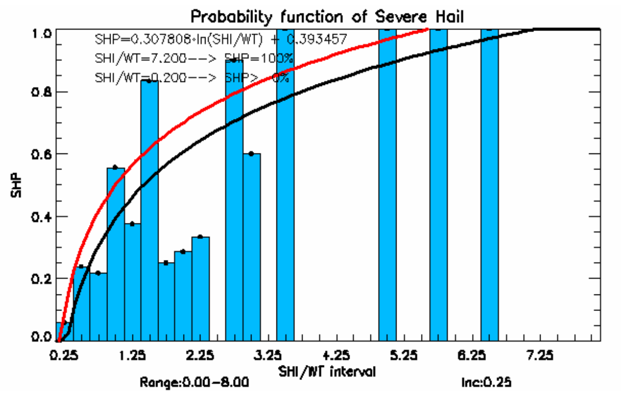

Fig. 4. SHP distribution for the region of Lleida, black line, and SHP distribution obtained by Witt et al. (1998), red line.

5 Conclusions

After analysing 17 hail events, a total number of 265 hail and no hail cells have been detected. Mean directions of the cells movement have no significant difference, with 15-21º (WSW-ENE) as the mean direction. Hail cells have displacements longer than no-hail cells, with mean values of 45km and 22km respectively. This fact agrees with the organisation degree of the precipitation systems with hail, which leads us to see the MUL system as those with the highest hail probability.

The WP parameter with an exponential distribution of hail probability is the best parameter to identify hail in surface. This result is different from the linear dependence on WP proposed by other authors (Holleman, 2001; Aran et al., in press) and it implies higher increase of hail probability with WP. When the hail's size is larger than 10 mm the best parameter is the adapted version of SHP for the region of Ebro Valley.

These results joined to the dependence found between some radar parameters lead us to apply a new methodology based on principal components analysis, in order to improve the distinction between hail and no-hail cells. Then, the methodology will be applied to realize a cluster analysis of all the 3D cells to model the life cycle of the radar parameters.

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References

Amburn, S. and P. Wolf, 1997: VIL Density as a Hail indicator. *Wea. Forecasting*, **12**, 473-478.

Aran, M., A. Sairouni, J. Bech, J. Toda, T. Rigo, J. Cunillera and J. Moré, in press: Pilot project for intensive surveillance of hail events in Terres de Ponent (Lleida). *Atmos. Res.*

Betts, A. K. and J. Miller: 1986. A new convective adjustment scheme Part II: Single column tests using GATE wave, OMEX, ATEX and Arctic air-mass data sets. *Quart. J. Roy. Meteor. Soc.*, **112**, 693-709.

Billet, J., M. DeLisi and B.G. Smith, 1997: Use of regression techniques to predict hail size and the probability of large hail. *Wea. Forecasting*, **12**, 154-164.

Brier, G.W., 1950: Verification of forecasts expressed in terms of probability. *Mon. Wea. Rev.*, **78**, 1-3

Ceperuelo, M., Llasat, M.C., T. Rigo, 2006: Rainfall events and Hailstorm Analysis Program, RHAP. *Ad. Geo.*, **7**, 205–213.

Dixon, M. and G. Wiener, 1993: Thunderstorm Identification, Tracking, Analysis and Nowcasting - A Radar-based Methodology. *J. Atmos. Oceanic Technol.*, **10**, 6, 785-797.

Donaldson, R. J., Jr., R. M. Dyer and M. J. Kraus, 1975: An objective evaluator of techniques for predicting severe weather events. *Preprints, Ninth Conf. on Severe Local Storms, Norman, OK, Amer. Meteor. Soc.*, 321–326.

Font, I., 1983: Climatic Atlas of Spain (in Spanish: Atlas Climático de España). INM and Ministerio de Transportes, Turismo y Comunicaciones, Madrid. 296pp.

Greene, D.R. and R.A. Clark, 1972: Vertically Integrated Liquid: a new analysis tool. *Mon. Wea. Rev.*, **100**, 548-552.

Grell, G.A., J. Dudhia and D.R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). *NCAR Technical Note*, NCAR/TN-398+STR.

Holleman, I., 2001: Hail detection using single-polarization radar, Scientific report WR-2001-01, Royal Netherlands Meteorological Institute (KNMI).

Johnson, J.Y., P.L. MacKeen, A. Witt, E.D. Mitchell, G.J. Stumpf, M.D. Eilts and K.W. Thomas, 1998: The Storm Cell Identification and Tracking (SCIT) Algorithm: An Enhanced WSR-88D Algorithm. *Wea. Forecasting*, **13**, 263–276.

Kain, J. S., and J. M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain-Fritsch scheme. The representation of cumulus convection in numerical models, K. A. Emanuel and D. J. Raymond, Eds., *Amer. Meteor. Soc. 2*46pp.

López, L., 2003: Convección atmosférica severa: pronóstico e identificación de tormentas con granizo. *Doctoral Thesis*, University of León, 207pp.

Pascual, R., 2002: Granizo en el llano de Lleida. *INM. Tempoweb training module*. Freely available at: http://www.inm.es/web/sup/ciencia/divulga/tempoweb/mcr6/index.htm.

Rigo, T. and M. C. Llasat, 2004: A methodology of convective structures using meteorological radar: application to heavy rainfall events on the Mediterranean coast of the Iberian Peninsula, *Nat. Hazards Earth Syst. Sci.*, **4**, 59–68.

Schleusener, R. A. and P. C. Jenings, 1960: An energy method for relative estimates of hail intensity. *Bull. Amer. Meteor. Soc.*, **41**, 372–376.

Waldvogel, A., B. Federer, P. Grimm, 1979: Criteria for the detection of hail. *J. Appl. Meteor.*, **16**, 1521-1525.

Waldvogel, A., B. Federer, W. Schmid and J. F. Mezeix, 1978: The kinetic energy of hailfalls. Part II. Radar and hailpads. *J. Appl. Meteor.*, **17**, 1680–1693.

Witt, A., M.D. Eilts, G. J. Stumpf, J.T. Johnson, E.D. Mitchell and K.W. Thomas, 1998: An enhanced hail detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 286–303.