A nowcasting tool for the analysis of the life cycle of rainfall structures using radar and lightning data

T., Rigo (1), J. Bech (1), N. Pineda (1), L. Trapero (1)
(1) Meteorological Service of Catalonia
tomeur@meteocat.com

INTRODUCTION

A radar-based nowcasting tool to identify, track and forecast precipitation has been developed and applied to a number of rainfall events. The system is fed with lightning (IC & CG) observations and a volumetric composite of reflectivity observations produced by the C-band weather radar network of the Catalan Meteorological Service. The tool is designed to support the weather surveillance and very short-range forecasting tasks of heavy rainfall events over Catalonia (NE of the Iberian Peninsula).

The tool generates different outputs, including 2-D and 3-D products. The 2-D radar product considers the lowest pseudo-CAPPI radar observations available and, after discrimination of stratiform and convective precipitation echoes, rainfall structures are identified according to a number of criteria such as horizontal reflectivity gradients and maximum extension. A similar 2-D product is built with lightning observations.

The 3-D product is obtained after examining the complete volumetric radar composite. Different reflectivity thresholds are applied to identify convective cell contours and centroids including characteristics such as area extension and echo top heights. The tracking and 1-h nowcasting of the precipitation structures in the 2-D and 3-D products is made considering cross-correlation between consecutive images and also NWP-model derived mid-level winds (700 hPa). Moreover, the evolution stage of convective cells (initiation, maturity and dissipation) in the 3-D product is also determined and forecasted.

The performance of the tool, currently in the verification stage, is examined with several precipitation episodes. For the selected cases, the life cycle of the structures is studied and compared with lightning data, with the aim to examine the different information provided by each observation type.

METHODOLOGY (1): Radar-derived structures

Using a 10-level CAPPI volume covering the area shown in Figure 1, and considering (1, 3, 5 & 10 km) model-derived wind forecasts, a number of procedures are applied with the following objectives (Circe & Martin, 2003, Johnson *et al.*, 1998, Rigo & Llasat, 2004, Rigo *et al.*, 2005, Steiner *et al.*, 1995):

- To identify and characterise precipitation structures in the lowest level, distinguishing convective precipitation (Fig. 2).
- To identify and characterise convective structures with vertical development (Fig. 2).
- To identify and track 2D structures from the previous 60' using cross correlation techniques (Fig. 2).
- To track 3D structures from the previous 30' following the centroid movement (Fig. 2).
- To analyse the life cycle of 2D structures.
- To analyse the life cycle of 3D structures (Fig. 6).
- To compute 60' forecasts of 2D structures using the observed field and NWP 850 hPa wind field forecasts.
- To compute 30' forecasts of 3D structures using the observed field and NWP 700 and 500 hPa wind field forecasts.

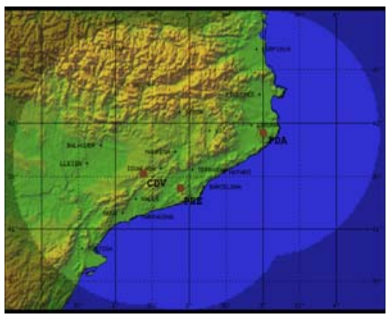

Figure 1. Coverage of the 3-D volumetric radar observations of the Meteorological Service of Catalonia radar network. Radar sites are indicated in red.

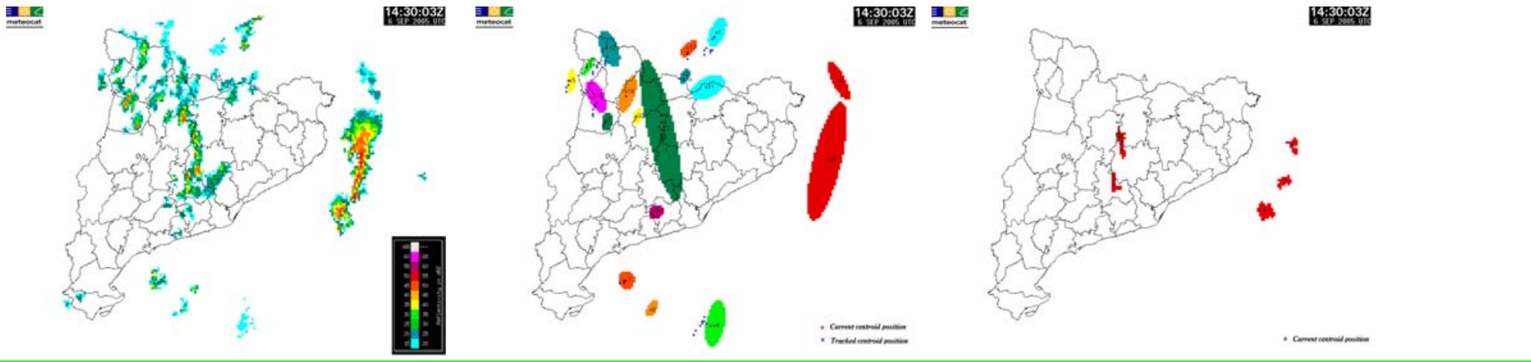

Figure 2. An example of radar reflectivity factor 1-km CAPPI composite (left); 2D structures, shown as ellipses displaying current and previous centroid position (centre); convective cells detected and their current centroid position (right).

METHODOLOGY (2): Lightning observations-derived structures

Considering lightning observations (IC & CG separately) recorded by the SMC (Pineda *et al.*, 2006) over the region of interest in a radar data acquisition cycle (6') and stored in an equivalent grid (aprox. 2x2 km2), a map of IC & CG flash density is built (Fig. 3). A similar approach is then applied as that described in the 2D radar structures, i.e.:

- To identify pixels of the map with a density higher than a given threshold (different for IC & CG) to group them in "lightning-structures"
- To characterise structures above a given area, "significant structures" (centroid, dimensions, high and low density, total flashes,.)
- To track the structures and analyse their life cycle.

A forecasting product of significant lightning structures similar to the 2D radar one is planned.

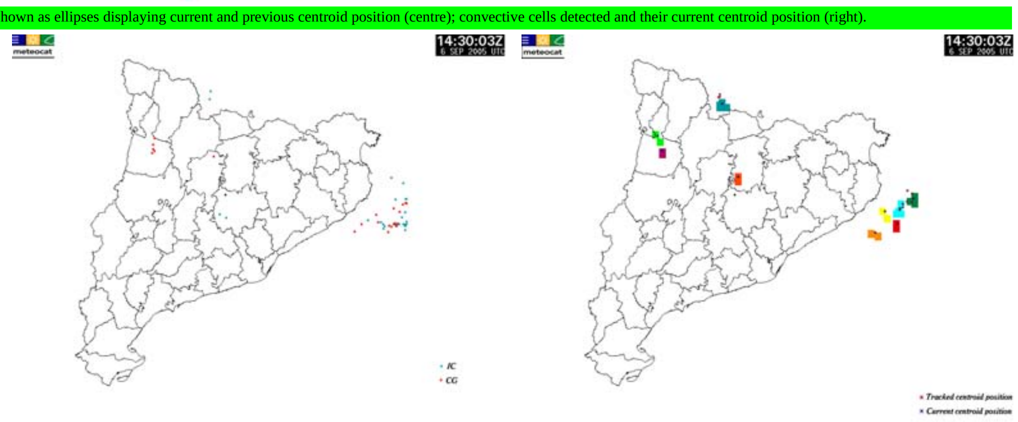

Figure 3. IC & CG observations corresponding to the radar image of Fig. 2 (left) and CG structures with their centroids (right).

CASE STUDIES

Two case-studies are presented to illustrate the application of the methodology described above:

06/09/2005: It was a widespread precipitation event, particularly relevant during the morning in the coastal area (between Barcelona and Tarragona, see Fig. 1) that later lead to a tornado outbreak (Bech et al. 2006). For this event the centroids of the different structures (2D and 3D radar, IC & CG) are displayed to evaluate the differences among them (Figure 4).

25/08/2006: It was a localised and brief but intense precipitation case, a typical example of flash-flood producing event in the Catalan coast during summer and autumn. In this case the life-cycle and the forecast of the 3D structure that caused the flash flooding is examined (Fig. 5, 6 & 7).

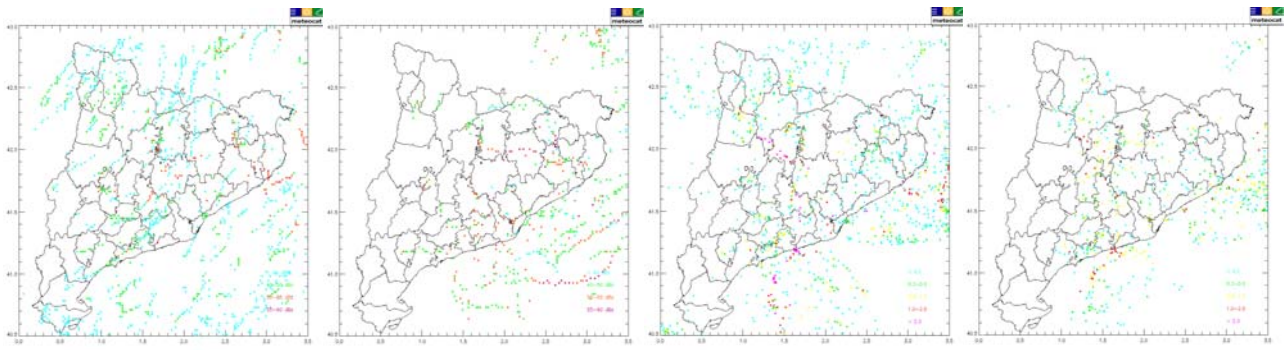

Figure 4. Centroid position of 2D-radar structures (left), 3D-radar (left-centre), IC (right-centre) & CG (right) corresponding to 06/09/2005.

06/09/2005

The direction of predominant movement was WSW to ENE in the morning and S to N in the afternoon, when the precipitation decreased substantially. The analysis of the spatial distribution of centroids of different structure types and their activity (flash density, reflectivity high values, etc.) seems to indicate a clear relationship between the 2D-radar and IC derived structures and also between 3D-radar and CG derived structures. Other remarkable aspects of the analysis are:

- A higher activity (higher centroid density) for all structures in the coastal area

- A displacement of lightning observations with respect to frontal part (E) of the radar-derived structures

- A high number of lightning-derived structures do not necessarily imply a high number of associated radar-derived structures (for example in front of the Tarragona coast)

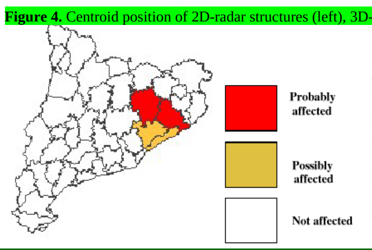

Figure 5. Map showing the official warning of areas affected by heavy rainfall -based on subjective interpretation of radar observations- issued by the SMC on the 25/08/2006.

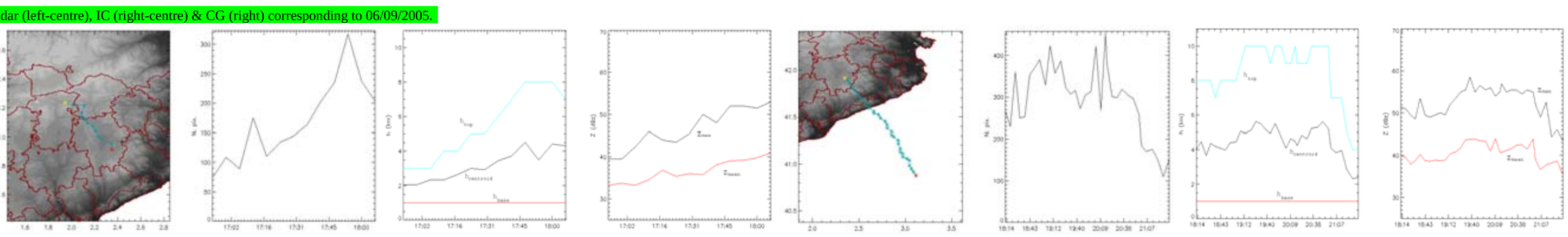

Figure 6. Life cycle (right to left: movement, pixel number, echo heights & reflectivity) of the structure that caused the flash-flood before 18:12 Z (left 4-figure pannel) and after 18:12 Z (right 4-figure pannel).

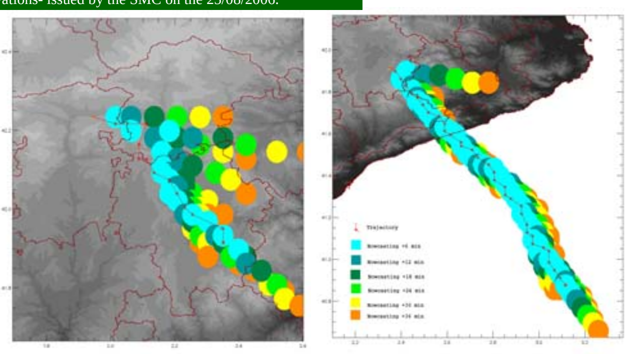

Figure 7. Nowcasting of the position of the convective structure shown in Fig. 6 before 18:12 Z (left) and after 18:12 Z (right).

25/08/2006

Figure 6 allows to remark some aspects of the life cycle of the structure that caused the flash-flood.

- The evolution of the number of pixels and echo heights indicates that it was not a typical single-cell storm (caused by a single updraft); several intensification and decay stages can be distinguished during the whole cycle. The structure lasted more than 4 h.
- Three different temporal stages can be distinguished: 1). Development (growth of all variables) and nearly random movements -probably induced by topographical factors-, ca. until 18 Z; 2). Mature stage (limited change of variables, except when approaching the sea -ca 19Z- when rainfall started over the flooded catchment) and stabilization of movement towards SE; 3). Dissipation stage (all variables decrease).
- Finally it should be mentioned that the speed of the structure was relatively high (40 km/h). Had the same structure been a quasy-stationary system, much severe flooding could be expected.

Regarding the nowcasting of the structure's position (Fig. 7) it should be said that during the first stage -particularly the first 18'-, due to the apparently chaotic movement of the track, the results were very limited. Later, in the second and third stages, the track became much more linear and predictable (some locations where very well forecasted 36' in advance). The warning (see Fig. 5) was issued upon examination of the observations corresponding to the first stage and a "Possibly Affected" risk was assigned to the county where the flooding finally occurred.

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CONCLUSIONS

- A nowcasting system to monitor radar precipitation structures has been developed and is currently being tested in pre-operational conditions.
- The system identifies, characterizes, tracks and nowcasts radar precipitation structures. A parallel methodology is applied to lightning data to obtain lightning-derived structures.
- Two different convective events (widespread and localised) were selected to illustrate the performance of the system.
- A clear relationship was found between radar and lightning derived structures: 2D low level radar-derived structures with IC structures and 3D radar data structures with CG structures.
- An spatial and temporal drift of the centroids of the different structures was observed: usually the maximum lightning activity preceded the maximum precipitation intensity. Moreover, both IC and CG structure centroids were located in the frontal part of the radar structures.
- A future version of the system is planned to integrate both the radar and the lightning structures in order to improve the characterisation of the life cycle of precipitation structures.

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