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Analysis of a complex rainfall episode in Catalonia on May 2005

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INTRODUCTION

A convective-stratiform rainfall episode occurred in Catalonia (Fig. 1; Fig. 2) on 16-17 May 2005 has been examined, focusing our attention on radar information. The more interesting feature of this storm was the mesoscale vortex developed at 17th 00 UTC, which could be related to the precipitation processes themselves. Its initial radius was 100 km but it expanded developing to a synoptic scale vortex six hours later. This mesoscale vortex induced new convection, modified low and midlevel flows and conditioned the dimensions, motion and, therefore, the persistence of the rainfall field.

The analysis of the NWP model operational at the Meteorological Service of Spain (INM) were not able to reproduce correctly this mesoscale cyclonic circulation and his evolution, although it generated a mesolow over the Catalonia-Balearic sea (200 km eastward/southeastward of the observed vortex) with its associated circulation, which could be linked to the main synoptic depression located 1000 km westward.

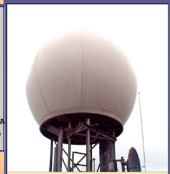
Hourly and daily rainfall accumulations of this event have been derived from radar information. A significant improvement could be observed from the comparison between raw and QC accumulation fields (especially, after correcting for radome attenuation). However, the effects of bright band contamination and path attenuation by rain remain in corrected fields and limit the quality of rainfall estimates from radar.

Fig.1. Catalonia situation at western Europe.

Band (cm)	C; λ = 5.4
Resolution (km)	Normal: 2 x 2. Doppler: 1 x 1
Range (km)	Normal: 240. Doppler: 120
Exploration Interval (min.)	10 both modes
Peak Power (kW)	250
Beamwidth (deg.)	0.9º
Pulselength (m)	Normal: 600. Doppler: 150

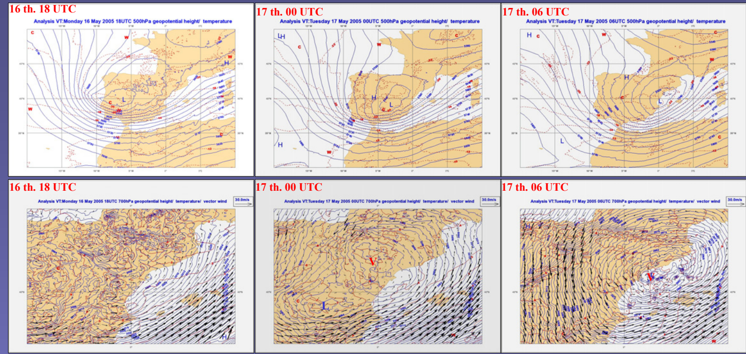
Table 1: Main characteristics of National Meteorological Institute (INM) radar at Catalonia.

Fig.2. Orographic map of Catalonia and surrounding areas indicating main features.



Radar INM in Catalonia: 654 m M.S.L, 20 km south-west from Barcelona city. Photo: INM

SYNOPTIC AND MESOSCALE ANALYSIS



A weakening cold front and a cold low (-28 ºC at 500 hPa) crossed the Iberian Peninsula from west to east between 16th 00 UTC and 17th 18 UTC. The low was well defined at 300 hPa, 500 hPa, 700 hPa and 850 hPa. Over Catalonia the minimum temperature at 500 hPa was -21 ºC. At 17th 00 UTC (Fig. 20) the 700 hPa geopotential height and wind fields analyzed by the 0.05º resolution HIRLAM model (operational in INM) showed two vorticity centers: one corresponding to the synoptic low (L) and the other developed a few hundred kilometers to the north (V). The 06 UTC analysis (Fig. 20) shows that both centers merged and displaced eastward, faster than vortices observed in radar and satellite imagery.

Fig.20. HIRLAM 0.05º analysis. Z and T. 500 hPa (top). Z, T and wind. 700 hPa (bottom).

EVENT DESCRIPTION (All times UTC)

1) 16th. 00-09. Eastward slow-moving stratiform band.

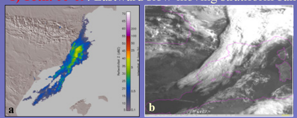


Fig.3. 16th. 0600. a) Z PPI0. b) MSAT-7. VIS.

2) 16th. 09-17. Eastward slow-moving stratiform band + widespread/no organized deep convection.

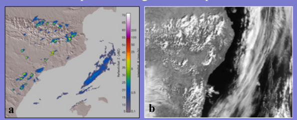


Fig.4. 16th. a) Z PPI0. 1200. b) NOAA 17, Channel 2, 1123.

3) 16th. 17-00. Residual showers, stratiform precipitation + small squall line (not shown).

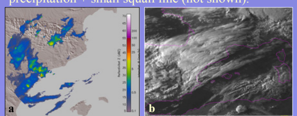


Fig.5. 16th. 1800. a) Z PPI0. b) MSAT-7. VIS.

4) 17th. 00-07. Convective-stratiform complex system with indication of mesoscale cyclonic circulation.

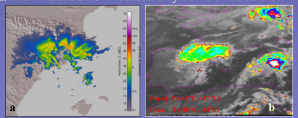


Fig.6. 17th. 0200. a) Z PPI0. b) MSAT-7. IR.

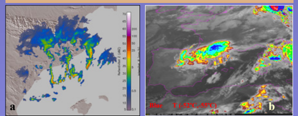


Fig.7. 17th. 0530. a) Z PPI0. b) MSAT-7. IR.

5) 17th. 07-11. Meso. cyclonic vortex + convection.

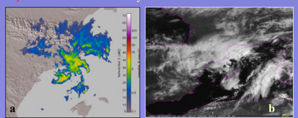


Fig.8. 17th. 0900. a) Z PPI0. b) MSAT-7. VIS.

6) 17th. 11-16. Mesoscale cyclonic vortex.

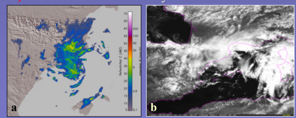


Fig.9. 17th. 1200. a) Z PPI0. b) MSAT-7. VIS.

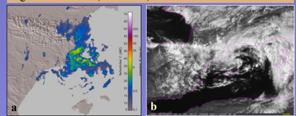


Fig.10. 17th. 1500. a) Z PPI0. b) MSAT-7. VIS.

7) 17th. 16-00. Precipitation ending

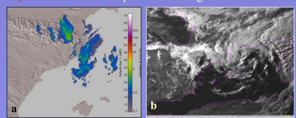


Fig.11. 17th. 1800. a) Z PPI0. b) MSAT-7. VIS.

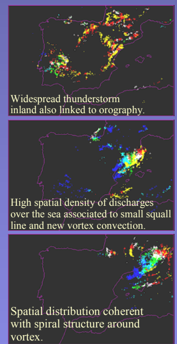


Fig. 12. CG discharges. 06-18 16th (top). 18-06 16th-17th (center). 06-18 17th (bottom).

RADAR ANALYSIS

Some quantitative results can be obtained from radar analysis to characterize event:

Previous step: Raw polar volumes correction. Control of radar signal stability outside the radome adding or substracting a factor to radar image. (Sempere-Torres *et al.*, 2003) (Fig. 13, Fig. 14).

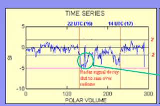


Fig.13. Stabi1ity index (SI) during event. Notice the general decay in middle event.

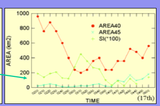


Fig.14. SI, area covered by Z ≥ 40 dBZ and Z ≥ 45 dBZ during the more attenuated stage.

Precipitating area evolution: Some meteorological stages can be identified but observational effects also affect its form (Fig. 15, Fig. 16).

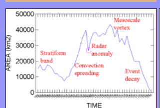


Fig.15. Time evolution (complete event) of area covered by Z ≥ 12 dBZ (0.5 mm/h according to M-P relationship).

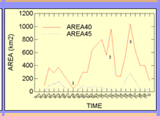


Fig.16. Time evolution (stage) of area covered by Z ≥ 40 dBZ and Z ≥ 45 dBZ. **1**: Convection decaying. **2**: Maximum associated to bright band. **3**: New convection associated to spiral vortex.

Persistence (Fig. 17):

Duration of rainfall associated to :

- Transient stratiform band.
- Widespread convection.
- Stratiform area associated to maritime squall line.
- New "cyclonic" convection.
- New "cyclonic" stratiform rainfall.

Some observational effects may be taken into account (numbers on image):

1) Maximum associated to stratiform precipitation (moderate intensity).
2) Convection + ground clutter associated to side lobes.
3) Deep convection + squall line.
4) Cell pattern associated to new vortex convection.
5) Radial symmetry associated to bright band and path attenuation.

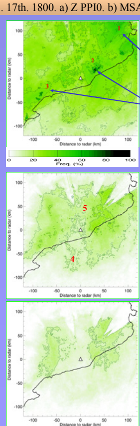


Fig.17. Persistence of reflectivity values above 12 (top), 25 (center) and 30 dBZ (bottom). % respect total of polar volumes. First contour depicted is 10 %.

Accumulation (Fig. 18, Fig. 19):

- Main maximum in northeastern Catalonia.
- Secondary maximum in coastal areas.

Corrections concerning: ground clutter, signal decay, orographic screening and VPR (with separation of precipitation type) have been applied to obtain radar accumulation.

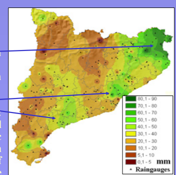


Fig.18. Spatial distribution of event total precipitation (2 days) in mm (contour interval 10 mm). INM raingages network. Obtained by Beatriz Tellez (CMT-Catalonia/INM).

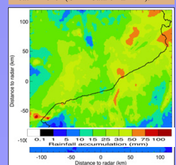


Fig.19. Accumulated rainfall (complete event) estimated from radar. Obtained by Maria Franco (GRAHI-UPC). (Franco *et al.*, 2005; Franco *et al.*, 2002).

MESOSCALE VORTEX INITIATION AND EVOLUTION

A mesoscale vortex was identified first in radar imagery (Fig. 21) and after in satellite imagery. Comparison between radar images from INM radars in Catalonia and Aragon (100 km westward) have shown that this vortex was located at middle levels (above 2000 m over the terrain). Detailed analysis of imagery and numerical model outputs seems to confirm that the vortex origin was related to the precipitation field itself but the conceptual model that explains the appearance of such a vortex in the stratiform area of a MCS (Houze, 2004) is not easy to apply in this case. The approaching (sub)synoptic cold low interacted later with the vortex and developed a greater structure.

From initial time to 04 UTC it is easy to follow the vortex with Z imagery but after this time, changes in Z field dimensions and pattern make difficult to identify it. Satellite imagery help to locate it between 04 UTC and 06 UTC (Fig. 22). In Fig 22 it is also possible to see the new convection developping eastward vortex center.

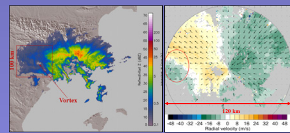


Fig.21. 17th. First vortex identification. 0130 UTC Z PPI0 (left). 0134 UTC Doppler wind, 0.6º elevation (right). Vortex center is outside Doppler domain (140 km from radar) but cyclonic circulation is visible near it.

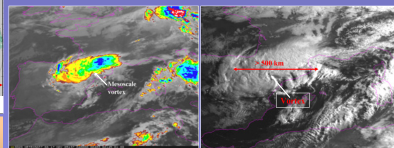


Fig.22. 17th. 0400 UTC MSAT-7 IR (left). 0600 UTC MSAT-7. VIS (right).

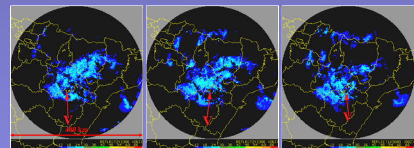


Fig.23. 17th. Z PPI0. INM Aragon radar. 06 UTC (left). 07 UTC (center). 08 UTC (right).

From 06 UTC to 08 UTC the evolution is more complex. From INM Aragon radar it is possible to follow southwestward vortex movement (Fig. 23), but motion fields obtained from Catalonia radar (Fig. 24) shows an opposite movement (to the east). After a detailed subjective analysis has been concluded that from 06 UTC two vortices can be discriminate: the first moving westward and disappeared in a short time and the second one moving eastward and growing to synoptic scale (> 1000 km diameter), as it is possible verify observing the spiral structure some hours later. From 08 UTC is easy again to follow vortex evolution from Z field, motion field and satellite imagery.

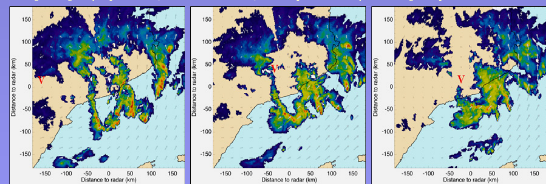


Fig.24. Precipitation motion field obtained from INM Catalonia radar. The algorithm implemented to estimate this field is based on *TREC* (*Tracking Radar Echoes by Correlation* -Rinehart and Garvey 1978-) to which continuity is imposed (in the way proposed by Li *et al*. 1995). The motion field is obtained with a resolution of 16 km and it is finally densified to the pixel resolution using linear interpolation. 17th 0600 UTC (left). 0700 UTC (center). 0800 UTC (right).

The extensive cold cloud shield (-40 ºC to -55 ºC), where mesoscale vortex developed, developed during the last hours of 16th from the merging of convective cells and stratiform areas. The small squall line developed at 20 UTC 16th also generated a stratiform area, contributing to the cloud shield growth.

Fig. 25 shows that at 0130 UTC 17th vorticity center associated to the cold low is located southward from mesoscale vortex, excluding the possibility that rotation perceptible in Z and cloud shield was associated to the transient cold low.

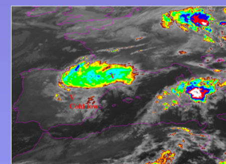


Fig.25. 17th. 0130 UTC MSAT-7 IR.

SOME VORTEX CHARACTERISTICS

Z and wind Doppler fields analysis shows that convective bands developped around vortex are converge lines (Fig. 26).

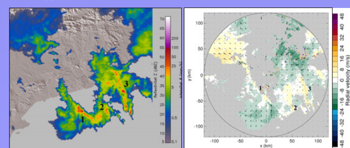


Fig.26. 17 th. 1720 UTC. Z field (left). Wind Doppler field (right). Numbers **1**, **2** and **3** point out three convergence/convective lines.

SUMMARY AND CONCLUSIONS

The complexity of the event was associated to:

- The synoptic evolution (1.- Cold front passing; 2.- Atlantic transient cold low; 3.- Mediterranean cyclogenesis).
- The diurnal cycle of convection and the presence of a sea/land boundary.
- The development of a mesoscale precipitation system with embedded convection (MCS not clear).
- The development of a middle level mesoscale vortex and his interaction with the synoptic wave.

More specifically the role of the mesoscale vortex has been:

- New convection generation over the sea.
- Rainfall persistence increasing in some areas.
- Flow changing at middle and low levels.

Radar data have been used in a variety of forms:

- Analysis of Z field (from single radar and national composition).
- Analysis of single radar Doppler wind field.
- Analysis of Z motion field.
- Analysis of accumulation.

NWP models reproduced only partially the evolution of mesoscale vortices.

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