P5C.2 ANALYSIS OF A STRONG SNOWSTORM IN CATALONIA ON DECEMBER 2001

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1. INTRODUCTION

A very complex winter precipitation event occurred on 14-15 December 2001 in Catalonia (in northeastern Iberian Peninsula). Snowfall accumulations of more than 20 cm were measured in many places, within which smaller pockets of accumulation in excess of 50-70 cm were measured in central Catalonia. This unusual snowfall created hazardous road conditions, hundreds of cars were cut off by the snow and it was six fatalities. Electrical supply was severely affected in a relatively large and very populated area, including Barcelona city.

The event, 40 hours long, was mainly characterized by a wide stratiform precipitation system, associated to a deep cold low centered west of Catalonia, and by a very persistent northeasterly cold advection at low levels. Synoptic pattern moved slowly, determining a quasi-stationary precipitation pattern. The important snowfall accumulation was consequence of both a high/moderate snowfall intensity and its persistence (see Doswell et al. 1996). At the beginning of the event the interaction between synoptic low-level northerly flow and the east-west oriented Pyrenees range resulted in the Tramontane-Mestral mesoscale winds system which determined a well established Catalonian-Balearic boundary layer Convergence-Zone (CBCZ) (Pascual and Callado 2002). The synoptic forcing associated to the upper-level disturbance reinforced the upward motion associated to the low-level convergence and rapidly transformed the previous cloudiness field in a precipitation field.

The Spanish National Weather Service (INM) has a Doppler radar in Catalonia located 20 km southwest of Barcelona city, and at 654 m amsl. Table 1 summarizes the principal characteristics of this radar.

Band (cm)	C (λ=5.4)	
Resolution (km)	Normal:2x2. Doppler:1x1.	
Range (km)	Normal:240. Doppler:120.	
Exploration Interval (min.)	10 (both modes).	
Peak Power (kW)	250	
Beam width (deg.)	0.9º	
Pulse lenght (m)	Normal: 600	Doppler: 150

Table 1. Main characteristics of INM Doppler radars.

2. SYNOPTIC AND MESOSCALE ANALYSIS

The upper-tropospheric synoptic pattern was characterized by an anomalous southwestward moving cold low, surrounded by two jet streaks and with a minimum temperature at 500 hPa of –36 ºC at 1200 14th Dec. (all times UTC). From 0000 to 1200 14th the low quickly moved from central Europe to northeastern Iberian Peninsula where it remained quasi-stationary for the rest of the event. Low at 700 hPa followed a similar trajectory, but it continued moving toward the southeast and after toward the east, changing the flow direction over Catalonia.

The lower-troposphere was characterized by a broad stationary low over western Mediterranean with a secondary low centered ~300 km east of Catalonia. The surface lows determined a persistent north–northeasterly synoptic flow over eastern Catalonia with a strong cold advection at the first day, that made the freezing level fall below 300 m amsl (0900-1500 14th), and a warm advection the next day.

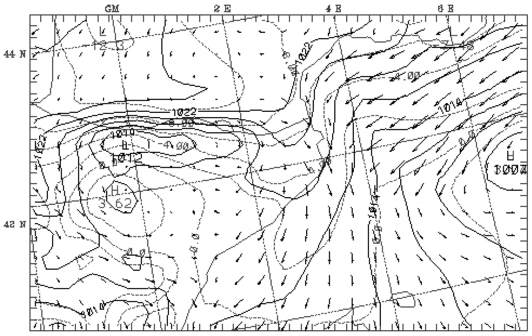

Fig. 1. MM5 analysis at 0900 UTC 14th. MSL pressure (solid lines every 2 hPa); wind at 10 m (vectors); temperature at 900 hPa (dotted lines every 2ºC).

The main mesoscale features were the CBCZ and a moist (80-90 % humidity) southeasterly low level jet (LLJ), briefly described in section 3.

At the first day, simultaneously to the cold surge, the CBCZ quickly developed between the dry northwesterly wind (Mestral) in southern Catalonia and the moist northeasterly wind (Tramontane) associated to the anticyclonic vortex generated at the eastern corner of the Pyrenees (Fig. 1).

The synoptic forcing associated to the upper-level disturbance reinforced the upward motion associated to the CBCZ. This low-level persistent convergence region probably supplied the vertical flux of moisture needed for the development and maintenance of the long-lived precipitation system.

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At the second day the mesoscale surface pressure pattern changed, disappearing the CBCZ, and strengthening the northeasterly wind.

3. RADAR ANALYSIS OF THE STRUCTURE AND EVOLUTION

The general evolution of the precipitation event is provided by the examination of radar reflectivity movie loop of first elevation (0.5º) PPIs (Trapp et al. 2001). The period of interest is from 0624 14th December to 2354 15th.

It is possible to identify three different stages in the evolution of the event:

- During the early stage (0624-1310) a very rapid development of a nearly circular stratiform precipitation area was identified. This area was almost stationary (see Fig. 2).

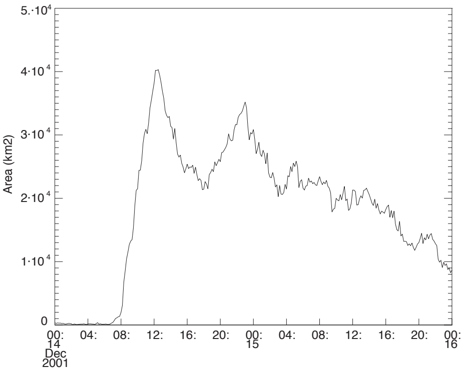

Fig. 2. Time evolution of the area covered by radar echoes with reflectivity of more than 12 dBZ.

- The second stage started with the development of a southeast-northwest-oriented enhanced reflectivity band. The western end of this band was clearly defined. The band was more than 200 km long and had a wide varying from 50 km to 100 km. The band persisted during the period 1310-2200, gradually changing its orientation to an east-west orientation but without any significant displacement of its center.
- The third stage (2200 14th-2354 15th) was characterized by a continuous development of precipitation cells defining a broken precipitation pattern. We call this period the “cellular stage”.

The movement of the radar echoes inside the band was first northwestward changing to westward and finally southwestward at the last stage, according to the evolution of the midlevel flow (850 hPa-700 hPa). We must emphasize that this movement was parallel to the band main axis, resulting in a kind of “stratiform train effect”, similar to what Doswell et al. (1996) described for convective events. The rotation of the system around an almost stationary center and the “train effect” leaded to a long duration of the snowfall. Areas with highest values of persistence of highest thresholds of reflectivity coincided with those where highest snowfall accumulations were reported. In central Catalonia reflectivity values above 5 dBZ persisted for more than 30 hours and for more than 12 hours above 25 dBZ. (Fig. 3).

Average reflectivity maps at first PPI for different time periods have also been calculated. This kind of maps shows the stationary or recurrent elements, as the cells of the last stage (showers) (Douglas et al. 1995). During the period 0624 14th-0024 15th averaged reflectivity values are slightly greater than 18 dBZ while from 0024 15 snowband, removing the transient ones as the individual th to the end of the event 12-18-dBZ averages were present. However, throughout these periods several hourly averages were between 30 dBZ and 36 dBZ, showing occasionally high snowfall rates but also some contamination by bright band.

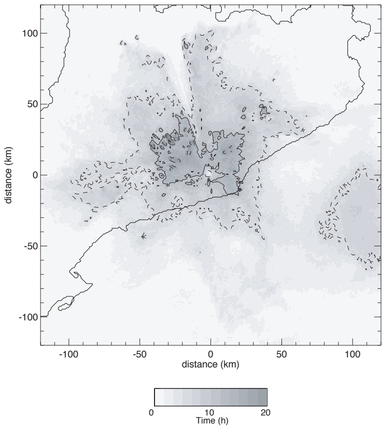

Fig. 3. Persistence of reflectivity values above 25 dBZ (dashed line 6 hours, solid line 12 hours).

The three-dimensional analysis of the volume scans (vertical cross sections and several CAPPI) has shown echotops (12 dBZ) lower than 2-3 km at the first and second stages and slightly higher at the last stage (4-5 km), in which some degree of convection associated with the warm advection in the lower troposphere was possible. This analysis has also shown that bright band was only present at the very beginning of the event, when cold advection affected only northeastern Catalonia, and in some moments of the “cellular stage”. These observations are consistent with the reported type of precipitation at ground and with the height of the freezing level showed by sounding data and model outputs (Section 2). The snowband presented in the second stage could be associated with the transition zone (Stewart 1992; Trapp et al. 2001) but low-level convergence was also present in this area. Of course, further analysis about this issue must be done.

Analysis of wind field with a single Doppler radar has a degree of ambiguity that make impossible to completely determine the kinematic aspects of an event. In spite of this some clues about it have been obtained.

Time-space averaged wind fields have been calculated for different time intervals (1, 2, 6, 12 and 24 hours) with the aim of filtering “anomalous” signals (positive velocities inside a broad-area of negative velocities and vice versa) and summarizing information. In these mean images the Tramontane-Mestral wind system and the associated boundary layer convergence zone can be identified during the first day. Over the next 24 hours the intensification of the low- and mid-levels northeasterly flow was evident.

Another interesting element that is visible in Doppler wind images from ~1000 to ~1600 14th is an easterly-southeasterly low-level jet (LLJ) above central Catalonia. At 1200 14th the Catalan Weather Service sounding at Barcelona showed a veering vertical wind profile with the velocity increasing from 14 km/h, 20º, at 98 m amsl to 58 km/h, 100º, at ~1000 m amsl and decreasing to 20 km/h, 165º, at ~2000 m amsl. The radar 0.6º velocity scan at 1204 measured a radial wind maximum of 65 km/h pointed to the radar in the vicinity of Barcelona (at a height of approximately 1 km amsl), coinciding with the core of the LLJ.

4. ACCUMULATIONS FROM RADAR

Raw polar reflectivity volumes have been corrected for ground echoes (identification and substitution –see Sanchez-Diezma, R. et al., 2001-), orographic screening effects and signal instability.

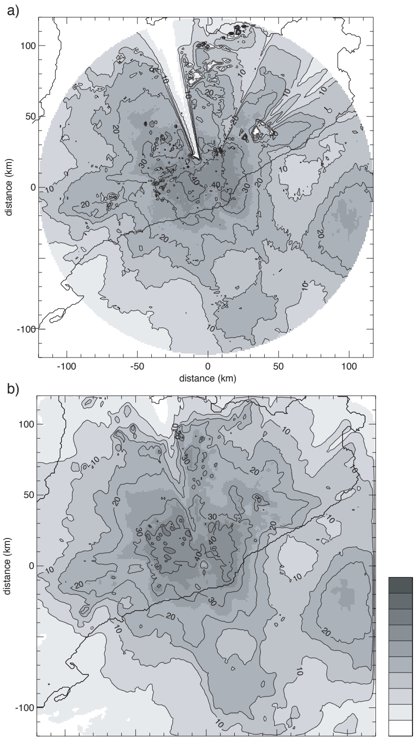

Fig. 4. Estimation of the accumulated rainfall along the event. a) Using hardware-corrected data without estimating the velocity of the precipitation field. b) Using software-corrected data and estimating the mean motion of the precipitation field with cross correlation.

A part of this study consisted in the generation of the accumulated rainfall field of the event from radar measurements (Fig. 4). This has been carried out with two different sources of data (hardware- or software-corrected reflectivity fields) and according to 2 different accumulation techniques (Bellon, A. et al., 1991):

- Simple sum of the measured lowest PPIs (keeping them stationary, assuming no velocity of the precipitation field).
- From the estimation of a mean motion velocity of the reflectivity field, and supposing linear evolution of intensities between two consecutive radar scans.

Accumulations calculated from radar data show the following phenomena: orography screening effects are not perfectly corrected (most of the times, at far ranges, signal is totally lost and cannot be recovered).

On the other hand, reflectivity substitution over ground clutter is quite well done (some pixels seem to remain slightly contaminated). A radial gradient of accumulated precipitation is also visible. This is mainly due to the vertical gradient of reflectivity (the precipitating layer was very thin) and to the increase of the radar sampling volume with range. Finally, in this case, differences due to the accumulation technique chosen are not important due to the uniformity of the precipitation field.

The field of accumulated precipitation obtained from radar is in quite good agreement with the registered values in rain gauges, especially close to the radar. At further ranges, radar tends to underestimate (as previously mentioned).

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