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The weather radar network of the Catalan Meteorological Service: description and applications

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Abstract. In autumn 2003 a new radar system was installed and included in the radar network of the Catalan Meteorological Service (SMC). It was the third unit of a network of four radars designed to cover the complex topographical area of Catalonia (approximately 32 000 square km), located in the NE of Spain. The initial design of the network was performed in 1997 considering the already existing weather radar installed in Vallirana (near Barcelona) in 1996. Using a propagation model, visibility maps were derived to study new potential radar sites aiming to minimize beam blockage problems to obtain an improved coverage area suitable for radar quantitative precipitation estimates. The high density of the radar network was calculated to improve the precipitation observing capacity in a highly complex topographical area prone to flooding according to the dominant torrential Mediterranean regime. From the initial network proposal, three new sites were evaluated and selected in the centre of Catalonia and in the northern and southern coast. Two new radars were installed in 2002 and 2003 and the remaining one is planned to be built during 2005. Some hardware characteristics of the first two systems were upgraded during 2003 so the radars are very similar from the technical point of view. They have an offset 4 m antenna dish providing a one-degree main lobe beamwidth. The antenna controller is the RCP-8 unit manufactured by Sigmet, Inc. The C-band transmitter, is based in a Travelling Wave Tube design, and is controlled by a digital Sigmet RVP-8 processor and receiver. Pulse compression is being implemented in 2004 to allow the use of long pulses with radial range resolutions similar to those obtained with higher power transmitters. The main application of the radar network is weather surveillance and monitoring of heavy precipitation events by the Catalan Meteorological Service in combination with other observational tools (lightning detection system, satellite images, etc.). Other applications, developed through collaboration research projects, include the assimilation of radar observations to improve precipitation forecasts of mesoscale NWP models and also the enhanced processing of radar data to allow its quantitative use in a specifically-designed hydrological model.

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1 Introduction

The Catalan Meteorological Service (SMC-Meteocat) is responsible for providing meteorological information to civil defence authorities of the autonomous region of Catalonia, according to current legal framework and a collaboration agreement with the Spanish Meteorological Institute (INM). Catalonia, with 32 000 square km, is located in the NE of Spain and has complex topography. The Pyrenees in the North exceed altitudes of 3000 m, and there are a number of other massifs and mountain ranges with different orientations, but mostly along the Mediterranean coast (SW to NE). Therefore, monitoring torrential rainfall events in this zone, which often produce flash-floods, is a rather challenging task.

The radar network was designed in 1997 (Belmonte et al., 1997) considering the already existing weather radar installed in Puig Bernat (Vallirana, near Barcelona) in 1996 by the University of Barcelona. Visibility maps were derived using a propagation model to study new potential radar sites aiming to minimize beam blockage in order to obtain an improved coverage, suitable for radar quantitative precipitation estimates. The relatively high density of the radar network was calculated to enhance the precipitation observing capacity in a complex topographical area prone to flooding according to the dominant torrential rainfall Mediterranean regime. From the initial network proposal, three new sites were evaluated and selected in the centre of Catalonia and in the northern and southern coast (Fig. 1). Two new radars were installed in 2002 (Puig d'Arques) and 2003 (Creu del Vent) and the remaining one (La Miranda) is planned to be built during 2005. Details of the radar sites are listed in Table 1. Several hardware characteristics of the first two systems, originally manufactured by Kavouras Inc., were upgraded during 2003. In particular, both the antenna controller and the digital

Table 1. Details of the radar sites (preliminary for LMI)

Code	Location	Longitude	Latitude	Altitude
PBE	Puig Bernat	1.88° E	41.37° N	610 m
PDA	Puig d'Arques	2.99° E	41.89° N	535 m
CDV	Creu del Vent	1.40° E	41.60° N	825 m
LMI	La Miranda	0.85°E	41.09° N	925 m

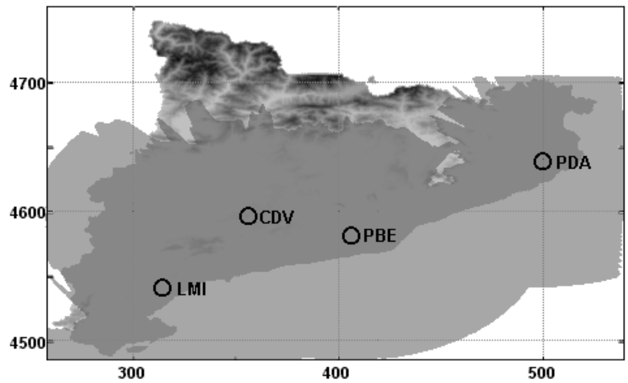

Fig. 1. Radar coverage of the network (with remarkable blockage in the North caused by the Pyrenees) considering only 0° antenna elevation PPIs.

receiver/processor were replaced by the RCP-8 and RVP-8 units from Sigmet, Inc. With this operation, these subsystems were identical to those of the third and fourth radar, manufactured by MCV, S.A..

2 Description of Radar Equipment

The radars of the Catalan radar network are all Doppler systems utilizing Travelling Wave Tube (TWT) transmitters, offset feed antenna, and a digital IF receiver/processor. The combination of these components provides a radar system of high coherency, superior side lobe characteristics and broad dynamic range, all of which are important qualities for a weather radar. A high level block diagram of the radar is depicted in Fig. 2.

2.1 Transmitter

The transmitters in the radars use a coherent TWT to produce the high power output. A TWT, like a klystron, is a pure amplifier in that it accepts a low power input and produces a high power output from this input. With such a transmitter, a waveform is generated at the radar intermediate frequency by the signal processor (RVP8) and upconverted to the radar RF and input into the TWT. By generating the original waveform in the signal processor, phase and/or frequency modulation can be introduced purposefully into the waveform to support various processing techniques upon echo reception.

The peak power of the TWT transmitters is typically limited to 8 kW, but average power of up to 320 watts can be achieved to support sensitivity comparable to a klystron of magnetron system. Signal processing techniques such as pulse compression are then used to make further gains in sensitivity through narrow filters, which also restore the range resolution to sub-microsecond values. Being low peak power, the transmitter is very small and easily maintained.

2.2 Antenna

The antenna used by the pedestal/antenna subsystem uses an offset feed design on all of the radars. Such a design provides for substantially lower side lobes as compared to a more traditional antenna with the feed in the centre of the parabola.

2.3 Receiver/Processor

The RF portion of the receiver is a low noise, high dynamic range linear design, but otherwise consists of a traditional single downconvertion stage. Because of this, there is no need for gain control circuitry often associated with weather radar receivers. The absence of gain control circuitry eliminates one major source of phase noise, thus providing for higher quality data and superior clutter.

Further minimizing phase noise is a digital STALO (STAble Local Oscillator). Digital stalos are frequency synthesizers that use a phase lock loop (PLL) to produce RF by multiplying up a base oscillator, in this case 10 MHz. The same 10 MHz signal is also connected directly to the signal processor so its trigger and sampling timing is synchronous with the 10 MHz base oscillator, further enhancing the coherency of the radar system.

The final part of this subsystem is the RVP8 digital IF receiver/processor (Passarelli and O'Hora, 2002). The RVP8 through its IFD (Intermediate Frequency Digitizer) samples the IF receive signal and an IF transmit sample signal. The transmit sample is used as a phase reference for doing Doppler processing. The output of the RVP8 is digital radar base data (Z, V, W) which are displayable on the local radar display computer and also sent over the network to the central radar computers in Barcelona via a TCP/IP based WAN connection. Control of the radars can be performed by the local computer, or also from the stations in Barcelona via the same TCP/IP WAN channel.

3 Pulse Compression in SMC Radars

In June 2004, the signal processing of the radars was enhanced with the addition of pulse compression. Pulse compression is a signal processing technique that allows for transmission of a long pulses using frequency modulation, and employs a filter on receive that "compresses" the pulse in time resulting in fine range resolution as expected with a short pulse (Mudukutore et al., 1998). At the same time as achieving this fine range resolution, the long pulse of a pulse compression system provides for much improved sensitivity

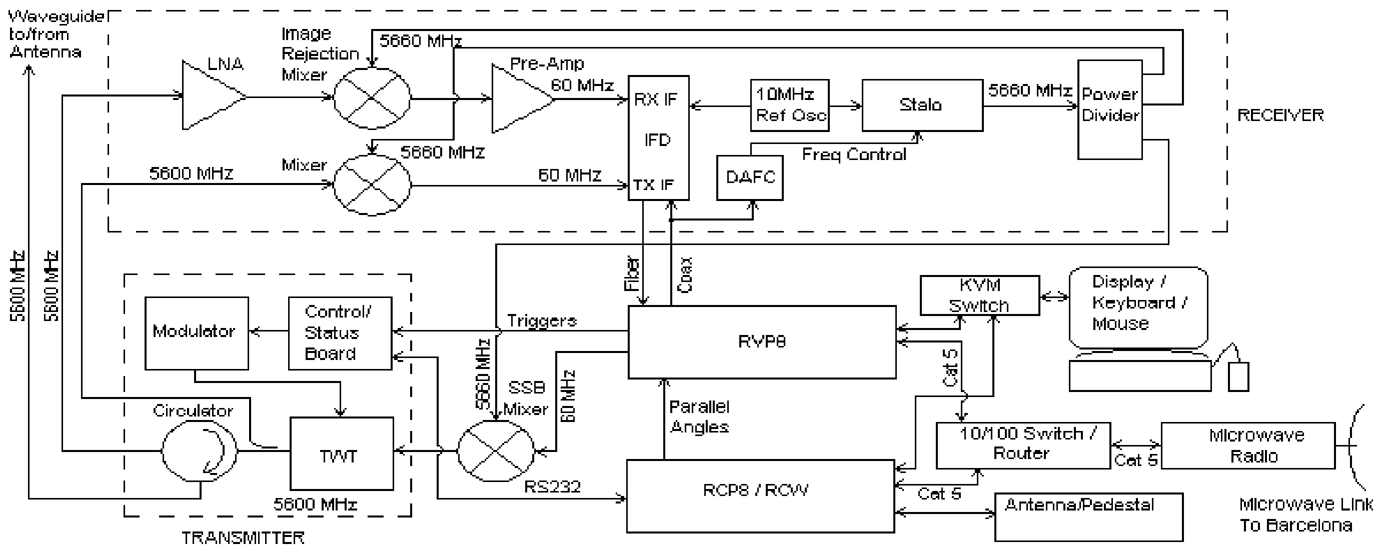

Fig. 2. Radar system block diagram.

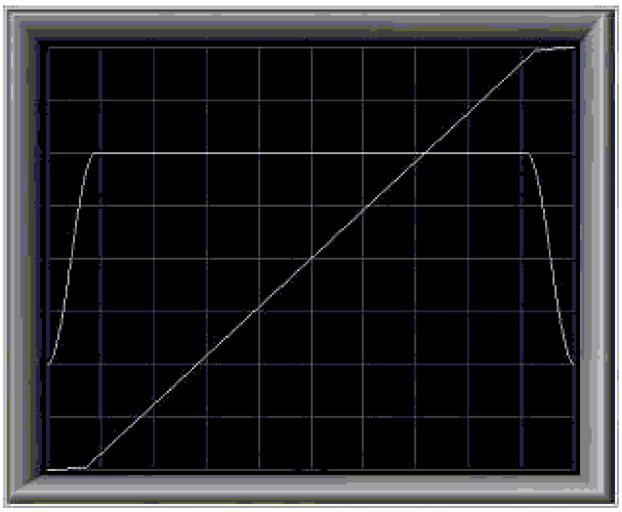

Fig. 3. Frequency modulation and amplitude tapering.

when compared to using a short pulse. In summary, pulse compression gives the range resolution of short pulses, but the greater sensitivity of long pulses. As the low peak power TWT transmitters of the radars can support a high duty cycle (4%), transmitting a long compressed pulse is practical and sensitivity comparable with high peak power transmitters is expected.

The first step in the pulse compression system is designing the appropriate long pulse frequency modulated waveform. The RVP8 signal processor used in the weather radars utilizes a digital waveform generation card called the RVP8/TX card. The RVP8/TX card generates the waveform digitally from sets of pre-computed coefficients and performs a D/A conversion to output the waveform at 60 MHz. This waveform is up-converted to the 5.6 GHz RF and sent to the TWT for transmission. The waveform can be designed using a graphical user interface of the RVP8 as pictured in Fig. 3.

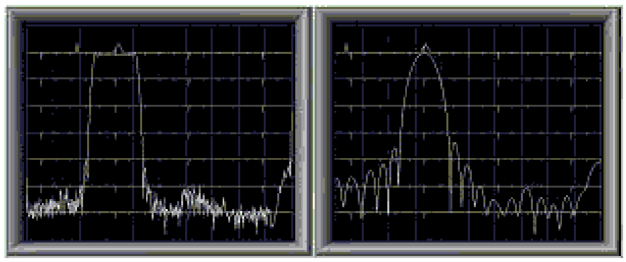

Fig. 4. Power spectrum of FM and standard pulses.

In this picture the sloping line depicts the frequency of the waveform. In this case, a non-linear FM pulse is chosen. At the beginning (left side) the frequency is increased slowly, then for the bulk of the pulse, it is increased steady and at the end, the increase is again slow. Also, as shown in the Gaussian shaped line, amplitude tapering is employed giving the pulse a "rounded" shape. This amplitude tapering greatly improves characteristic such a range/time sidelobes and keeps the frequencies confined to a narrow band.

In Fig. 4 (image on the left) is shown the frequency plot of 40 microsecond compressed pulse with 3 MHz of frequency modulation. On the right is shown the frequency plot of a 1.2 microsecond standard pulse. In each case the plot extends from 54 MHz on the left to 72 MHz on the right. The centre of both pulses is at 60 MHz. The compressed pulse has a very concentrated and flat use of power over 3 MHz of bandwidth while the short non-compressed pulse has a tighter peak of power at the centre frequency, but more distinct frequency side lobes.

Finally, the following three plots (Fig. 5) are time based instead of frequency based. Each plot shows the received

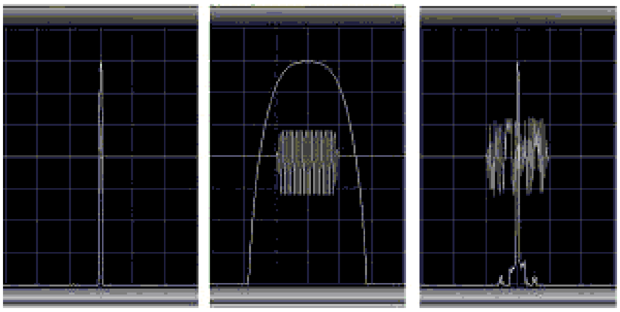

Fig. 5. Different raw and processed received signals.

signal resulting from transmitting various pulses. The raw received signal is shown in vertically centered, and the processed receive signal is shown in extending up from the bottom axis. The processed signal is most interesting.

In each case, the x-axis division between lines is 20 microseconds and the y-axis divisions are 10 dB. The first plot is from a 1.2 microsecond pulse. The raw signal and processed signal are the same length (1.2 microseconds). The second plot shows a 40 microsecond non-compressed (unmodulated) pulse. In this case the peak energy is spread over the full length of the pulse. The third plot is a 40 microsecond pulse with 3 MHz of FM. In this case, the pulse is compressed by a factor of 120 to about 0.35 microseconds providing a range resolution of about 50 m. Range / Time side lobes are suppressed more than 60 dB, but sensitivity would be nearly equal to the 40 microsecond non-compressed pulse shown in the middle figure.

4 Applications overview

The main purpose of the radar network is to provide a powerful tool for operational precipitation monitoring. In the last years, a number of studies and developments have been devoted to different aspects of this task, including disdrometric measurements (Cerro et al., 1997), anomalous propagation analysis and its effects (Bech et al., 2000; Bech et al., 2003), comparisons between radar and lightning observations (Pineda et al., 2004) or the study of convective structures (Rigo and Llasat, 2004). For example, Fig. 6 shows three elements considered in the analysis of convective structures: the lowest 1 km CAPPI, vertically integrated liquid (VIL) and 12 dBZ echo top height, as observed by the PBE radar, and lightning observations. Based in this diagnostic, a cell tracking and extrapolation procedure is currently under development.

Other applications of radar observations aimed at the improvement of NWP products trough different assimilation techniques. During the recent DARTH and the current CARPEDIEM EU research projects, both satellite and radar reflectivity observations of the Vallirana radar were used to improve the moisture representation of the MASS model (Codina et al., 1997; Codina et al., 1999; Picanyol et al., 2004).

Finally, regarding hydrological applications, a hydrometeorological real-time flood warning system, EHIMI, has been planned and developed (Sánchez-Diezma et al., 2002). The project, currently in its final implementation stage, is funded by the Catalan Water Agency. It includes a set of corrections to provide high quality radar precipitation estimates and a coupled hydrological model fed by both radar and rain gauge observations covering the catchment of the Besós river, within the Barcelona metropolitan area. Besides, future projects include the participation of this radar network as a ground validation super-site for the satellite based Global Precipitation Measurement (GPM) Mission.

5 Summary and conclusions

This paper provides a technical description of the Doppler radar network of the Catalan Meteorological Service. The network operates in a highly complex topographical area affected by a torrential Mediterranean rainfall regime. Details covered include the geographical distribution of the radar sites and also a description of the technical characteristics of the radar systems. Special emphasis is given to a recent upgrade in the radars consisting in the implementation of pulse compression capability. Pulse compression allows similar or better radial resolution and sensitivity than that obtained with standard high power transmitters, but using low power transmitters with Travelling Wave Tubes (TWT) and long pulses.

Besides, a quick review of the applications of the network performed with the radar observations is given to outline the wide range of related projects that the network has generated (from nowcasting to NWP assimilation and hydrological applications).

Regarding the future of the radar network, the current collaboration agreement with the Spanish Meteorological Institute (INM), considers the exchange of weather products such as radar observations of the INM radar network (Aguado et al., 1994; Camacho, 1999). This would extend real time access to data of neighbouring areas and, therefore, further improvement in coverage limitations due to beam blockage and overshooting could be achieved. Another topic under consideration, after the last fourth radar installation planned for 2005 is completed, is the upgrade of one of the radars with polarimetric capabilities.

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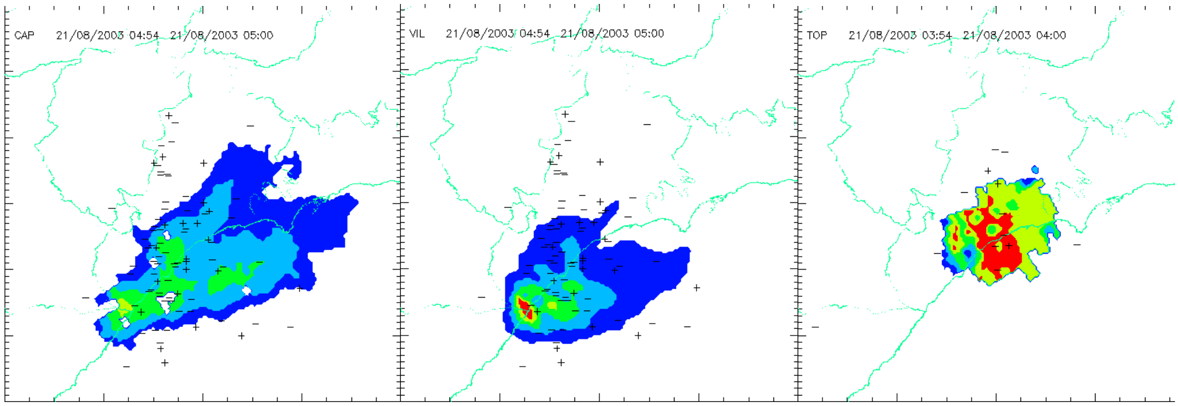

Fig. 6. Elements considered in the analysis of convective structures: lowest 1 km CAPPI (left), VIL (centre) and 12 dBZ echo top height (right) observed with the PBE radar and lightning flashes.

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