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Polar 55C: an upgraded instrument for polarimetric radar research

E. Gorgucci[1], **L. Baldini**[1], **and A. Volpi**[2]

[1]Institute of Atmospheric Sciences and Climate – CNR, via Fosso del Cavaliere, 100, Roma, Italy
[2]Eldes Lassen International, via di Vittorio 5/40, 50145 Florence, Italy

Abstract. The radar meteorology group of the Institute of Atmospheric Sciences and Climate (ISAC), the former Institute of Atmospheric Physics of the Italian National Council of the Research (CNR) employs the POLAR 55C radar system in the field of meteorological and hydrological application of radar polarimetry. The system is a coherent C-band Doppler dual polarization radar, which has been continuously upgraded through an evolution process so that the radar can be used for state of the art research in radar meteorology. The system operated in the Montagnana site, near Florence, Italy, for the Arno Project and MAP campaigns for radar rainfall estimation. During 2001, the system was moved from Montagnana to the Tor Vergata Research area of CNR, located 20 km South-East of downtown Rome and installed on the roof of the tower of the ISAC building. The system has been completely overhauled, both in microwave and mechanical sub systems. Above all, the radar is now equipped with a new digital receiver, as part of a new Radar Signal Processor, and new software for system operation control, data handling and displaying. From the current site, the POLAR 55C can monitor precipitation over the farthest part of the Tevere basin, the urban area of Rome, and the central Appennines. The paper illustrates the main features presently available in the POLAR 55C radar system, with particular emphasis to the most recent upgrades and their evaluation in the context of polarimetric radar research. Improvement in system performance is presented with examples of radar observations.

1 Introduction

The exploitation of radar polarimetry to improve quantitative rainfall estimation and to estimate parameters characterizing the microphysics of precipitation is gaining increasing interest among the radar meteorology community and is also the main scientific interest of the radar meteorology group of the Institute of Atmospheric Sciences and Climate (ISAC), the former Institute of Atmospheric Physics of the Italian National Council of the Research (CNR). From the beginning of the 90s, the research activity of this group took advantage of the availability of the POLAR 55C radar system. This coherent dual polarimetric radar was conceived during the 80s, when, in Italy, the need of new radar instruments, specifically tailored for advanced studies in the emerging research issues of Doppler and Polarimetry in Cloud and precipitation physics was expressed. The radar was first installed in the Montagnana site, near Florence, Italy. The radar was employed in several campaigns, mainly focused on the exploitation of polarimetric radar techniques to the improvement of flash flood forecasting systems within the Arno Project, promoted by the National Group for the Defense from Hydrogeological Disasters (Baldini et al., 1995; Gorgucci et al., 1996). In 1999, when the RSP software was upgraded in order to provide differential phase shift estimates, the POLAR 55C was among the radar systems participating in the Mesoscale Alpine Programme campaign (Bougeault et al., 2001). In 2001, it was moved to the Tor Vergata Research area of CNR, located 20 km South-East of downtown Rome. A more complete upgrade has been planned and implemented during 2001 and 2002.

The present paper, after a short review of the POLAR 55C history, describes current features of the system, with particular emphasis on the recent upgrades. The next part describes the radar site, with reference to climatic features of the monitored area and the quality of radar coverage. Finally, some examples of recent observation from the new site are presented.

2 The radar system

In the early 80's, CNR, in order to carry out research in the most advanced topics in radar meteorology, in particular in polarimetry, planned in cooperation with IDS (Ingegneria dei Sistemi, Pisa, Italy) a new C-band "coherent, frequency-agile, dual channel, polarization diversity radar (Leonardi et

Correspondence to: E. Gorgucci
(gorgucci@radar.ifa.rm.cnr.it)

al., 1991). The proposed system was based on an antenna system and servo by EEC (Enterprise Electronics Company, Alabama, USA) and the receiver/transmitter apparatus designed and produced by SMA (Segnalamento Marittimo ed Aereo, Florence, Italy). This apparatus was the base of that adopted later by SMA in the GPM 500C series of operational Doppler dual polarization radars, employed by several regional weather services and Air Force as well in Italy.

SP20 by Lassen Researches was adopted as the Radar Signal Processor (RSP). The system RSP implemented software for real time extraction of Reflectivity Factor (Z_h), Differential Reflectivity (Z_{dr}), mean velocity (v) and the second central moment of the Doppler Spectrum (σ_v). Software also included Doppler filtering for ground clutter rejection capability. The radar system was conceived as a portable one. Power and receiver/transmitter apparatus were located in a shelter, while a second shelter contained signal and data processing, transmission and displaying equipment. The radar system was thus installed in 1991 in the Montagnana Site, located 17 km South of Florence (Italy), in order to provide radar measurements to the Arno Project, a project promoted by GNDCI, which aimed at devising an advanced system for flash flood forecasting.

The radar operated with three pulse lengths, 0.5 - 1.5 - 3.0 μs and three corresponding pulse repetition frequencies (PRF), 1200 - 600 - 300 Hz. Only Z_h estimates were allowed for longer pulses, while, several processing modes for computing of Doppler and Z_{dr} parameters were available for the shortest pulse. Details of the adopted radar system configuration and a description of the Arno Project can be found in Scarchilli et al. (1991). Operations at the Montagnana site were managed through a cooperative agreement between the Departments of Civil and Electronics Engineering of the University of Florence and SMA, which was initially in charge of technical support and also provided the Montagnana Site itself. During 10 years of operation, the system was upgraded in order to improve the management of campaigns, real time data display and data delivery. To this purpose, a radio link, supporting the TCP/IP protocol, was set up in order to transmit data to the University of Florence. The major improvement took place in 1999, where a new mode, named PHIDP MODE, was implemented on the RSP in order to allow real time estimate of the differential phase shift. In such mode, available for short pulse (0.5 μs), the RSP extracts from an alternating sequence, Z_h Z_{dr}, v and σ_v. This mode was widely tested and utilized during the MAP campaign.

During 2001, the system was moved from Montagnana to the Tor Vergata Research area of CNR, located 20 km southeast of downtown Rome, over the ISAC building. In the meanwhile, the system has been completely overhauled, both in microwave path and mechanical sub systems. The radar system was installed in accord with the same configuration adopted in Montagnana. Figure 1 shows the buildings of the Tor Vergata Research area surmounted by the POLAR 55C antenna. Servo, transmitter and receiver systems and the microwave package are installed in a place just under the roof of the building. Operators can control the radar from a different operating room located in the East side of the building. Finally, the most recent and relevant upgrade of the system consisted of replacing the whole receiver-processing chain, including both the SMA receiver/transmitter and the SP20 by the Weather Radar Upgrade Kit provided by Eldes Lassen International (Florence, Italy), and in substituting the old real time display and radar command facilities with that produced by the same provider. The next sections describe in detail the features of the system in the current POLAR 55C configuration. Figure 2 shows a simplified block diagram of the system which highlights the upgrades and the legacy constituted by the microwave package, servo/antenna system, and the power transmission system.

Fig. 1. The Polar 55C antenna to be installed over the top of the building of ISAC, in the Tor Vergata Area of the National Council of the Research.

2.1 Antenna and microwave package

The antenna was not changed from the Montagnana installation, since it was conceived in order to provide optimal performance for polarimetric research. The single off-set geometry of the antenna was chosen in order to avoid beam blocking by stalls which could both increase the cross-polarization level and cause differences in radiation patterns in H and V polarizations. The same requirement suggested avoiding the use of a radome, even if it would increase the stress of the mechanics of the servo antenna. An orthomode transducer,

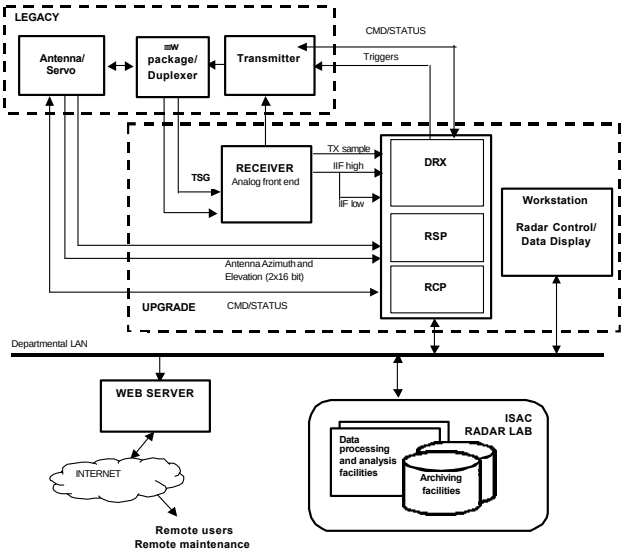

Fig. 2. Block diagram of the POLAR 55C system.

integrated with the feeder, is connected through waveguides to the microwave switch, which is indoors and placed just below the antenna pedestal basement in order to make it work in a controllable environment and to reduce the length of microwave paths and correspondingly increasing the sensitivity with respect to the previous installation. The switch is a high power ferrite type that permits a -27 dB isolation level which is considered appropriate for co-polar measurements. Table 1 summarizes the main features of the described subsystems.

2.2 Radar receiver/transmitter apparatus

POLAR 55C implements a single receiver. The radar receiver/transmitter apparatus is a fully coherent one. The power end of the transmitter did not change from the previous configuration. The transmitter is based on a klystron amplifier which allows for very high pulse-to-pulse and phase stability. The klystron uses a very high peak power in a derated condition. The transmitter can operate with three different pulse lengths (0.5, 1.5, 3.0 μs) at three corresponding PRFs (1200, 600 and 300 Hz). In the new configuration, the transmission is piloted by the up conversion chain available with the upgrade kit, which generates the drive signal of the transmitter. In order to set both the PRF and pulse length, the DRX component has to generate a gate signal which on/off modulates the drive signal. In the POLAR 55C implementation, this feature was limited within duty cycle limits allowed by the analog receiver front end.

Received signal is down converted two times in order to achieve the 10 MHz Intermediate Frequency (IF). The IF signal is filtered and sampled at 40 MHz, passed to a real-to-complex converter, and finally decimated to provide 10 M samples per second of In-phase and Quadrature components. This processor performs these functions in two receiver channels (one high sensitivity and one low-sensitivity channel). The DRX implements an algorithm for selecting the proper channel in order to avoid saturation to obtain the highest possible signal-to-noise ratio. A high pass filter, with a selectable cut off frequency, can be optionally inserted by the operator to reject ground clutter. A similar approach to upgrade the radar system was followed also at the Colorado State University CHILL facility; details and additional information about the DRX functioning and performance, here omitted for brevity can be found in Brunkow et al. (2000). It is possible to quantify advantages obtained by the new apparatus both in terms of Noise Figure, which has been reduced from 5 dB to 2 dB, thus enhancing the capability of detecting low reflectivity particles and for clear air observation, and in terms dynamic range which has been extended to over 100 dB from the 90 dB of the previous system.

Table 1.

Antenna characteristics	
Type	Offset fed Paraboloid
Feed	Corrugated horn
Aperture diameter	4.57 m
Polarization	Horizontal and Vertical
Azimuth beamwidth	0.92 deg
Elevation beamwidth	1.02 deg
Gain	45.5 dB
Sidelobe level	-32 dB
Cross Polarization	-27 dB

2.3 Radar Signal Processor

The implementation of the Radar Signal Processor (RSP) is based on a commercial off the shelf VME card equipped with two SHARC DSPs manufactured by Analog Devices. In the configuration adopted for the POLAR 55C, the RSP implements algorithms for real time calibration and correction, calculation of Z_h, Z_{dr}, v, σ_v and ϕ_{dp}, and Doppler filtering. The RSP is interfaced through a VME backpane to the Radar Control Processor.

As far as calibration and correction are concerned, RSP can exploit the sampling of the transmitted waveform, in order to correct amplitude and phase pulse by pulse. The rate of products generation can be synchronized with antenna movement, in order to generate radar data according to a given azimuth resolution, or with the number integrated pulses. 2000 range bins are now available for outputs; only 980 were available with SP20 and for example, with a pulse length of 0.5 μs and 1200 Hz PRF, it would not be possible to have data to the maximum radar range without resorting to range averaging. Further flexibility is due to the possibility to select the position of the initial range bin.

The availability of a developmental environment, based on the C programming language, of SHARC DSPs highly improve the maintainability of the POLAR 55C RSP with

Table 2.

Transmitter characteristics	
Power Amplifier	Klystron VCK 7762
Frequency	Fixed, selectable in the band 5600–5650 MHz
Peak Power	500 kW
Pulse width (maximum)	0.5-1.5–3.0 μs
PRF	1200–600–300 Hz
Average Power	300–450–450 W
Available polarizations	H and V

Table 3.

Receiver characteristics	
Number of channels	2: (RX and TX sample down conversion to IF)
Noise figure	2.0 dB from the input of the first down conversion module
Image Rejection	$>$50 dB
Dynamic range	$>$100 dB at 1 dB compression
IF	10 MHz
IF bandwidth	2.0–0.7–0.5 MHz

respect to the previously adopted SP20 which required the knowledge of a specific low level programming language.

2.4 Radar Control Processor

This unit acts as the interface of the radar system to external hosts. The Radar Control Processor is equipped with a Fast Ethernet Port and communications with external hosts are based on the TCP/IP protocol and a client-server architecture. Communications with other components of the radar systems are made through serial lines, while the connection with the RSP is provided through the VME backpane. This unit also manages the available built-in test equipment.

2.5 Data displaying, system control, archiving and data distribution

A Sunblade 1000 workstation, connected to the existing Departmental LAN accommodates the user interface for real time data display and system control. The available data presentation modes are:

- PPI mode;
- RHI mode;
- A-scope.

A data acquisition scheduler is part of the software package. In-phase and Quadrature components of receiver outputs are also available at the end of the receiver. Data are organized in files. Each one corresponding to the fixed angle of the selected scan strategy (i.e. elevation for PPI scans) and can be archived in the available mass storage systems. Data can be shared through the Departmental LAN by the workstations of the laboratory of the Radar Meteorology group, where software for data processing and data conversion (i.e. to Universal Doppler Exchange Format, Barnes, 1980) is available. The Internet connection of the ISAC can be adopted both for disseminating data, and for remote maintenance. Available software includes widely known tools for radar meteorology data analysis like SOLO, CEDRIC and REORDER (developed by the National Center for Atmospheric Research, Boulder, USA and downloadable from http://www.atd.ucar.edu/software.html). Policy and tools to disseminate POLAR 55C radar data through the Internet, according to the need of categories of user (Internet users, researchers, Civil Protection Departments).

3 Observed area

The exact position of the POLAR 55C corresponds to North Latitude 41° 50′ 24”, East Longitude 12° 38′ 50” and a height of 102 m. Figure 3 shows reflectivity observed at an elevation angle of 1.04° on 6 June 2002. The position of Rome can be referenced by the circle, which represents the highway that surrounds it. The coastal line, Tiber River and its main tributary can also be seen in this map. The observable region is a hilly one. Main limitations to visibility are constituted by Monte Cavo, located few kilometers south of the radar site, by the two minor hills of Monti Prenestini and Monti Sabini located 20 km in direction E–NE, and finally by the tall Terminillo Mount, located 70 km from the radar site along the N–NE direction. The occultation constituted by Monte Cavo is total and determines the presence of an occulted sector, from 120° to 150°, recognizable in the map. Good visibility in the north west sector allows the monitoring of precipitation over the Tyrrhenian Sea, which is very important in order to understand the advection of the precipitation to the urban area of Rome and to predict incoming precipitation cells over that area. As far as the climate is concerned, annual precipitation over the Rome region is about 750 mm; most of the precipitation occurring during the Fall months. In the region, a radar dense network of about thirty tipping bucket raingauges, with 1 min time resolution, is available and can be used for validation purposes.

In spite of mountains, which determine the limitation in radar visibility of the region in some sectors, it is possible to achieve a good monitoring of precipitation in the Appennins Mountains, where interesting observations of convective storms, which frequently occur there during the summer, can be made. Figure 4 provides an example of an RHI observation of convective cells in that area. It is possible to see the vertical extension of the cell, which can reach more than 10 km.

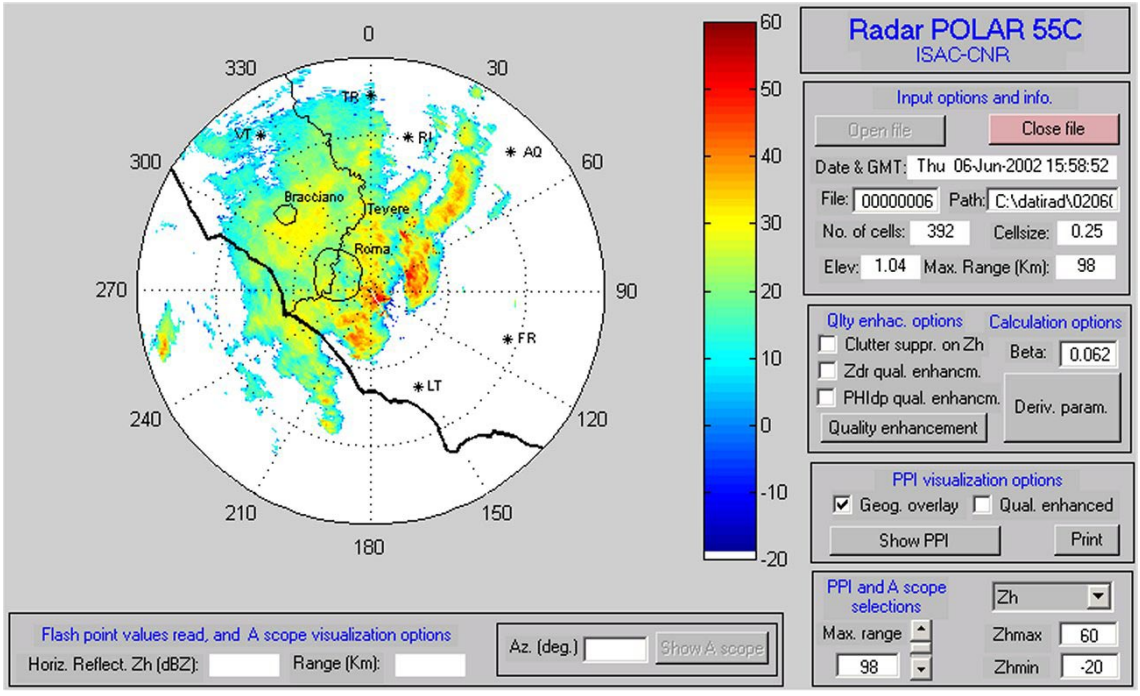

Fig. 3. Reflectivity map (elevation = 1.04°).

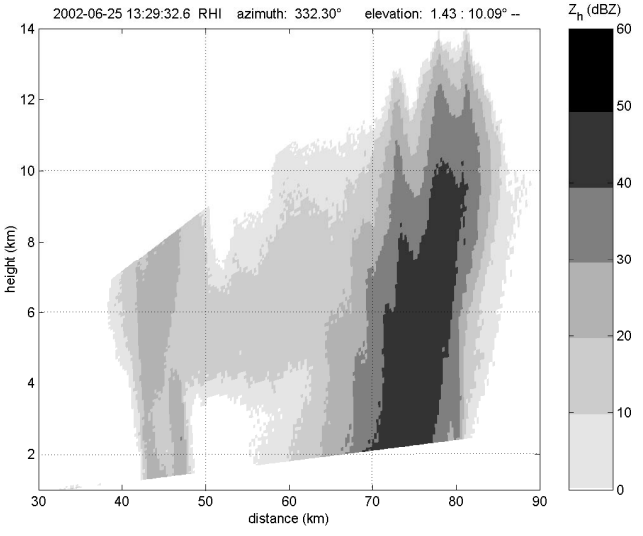

Fig. 4. RHI observation of a summer storm over the Central Appennines.

4 Summary

The POLAR 55C, recently updated and enhanced through the adoption of a new Digital Receiver, a new Digital Signal Processor and new software for radar control and data displaying, as described in the present paper, is now working in the new site of Rome in the "Tor Vergata" Research area of CNR. Major upgrades are related to the performance and functionalities of the new Transmitter/receiver apparatus and Radar Signal Processor as well. The first one take advantage from digital receiver technology. An extension of the dynamic range up to 100 dB and 3 dB enhancement of the noise figure has been achieved, which allow to employ POLAR 55C for detection of low reflectivity and near clear air echoes. Main functionalities of the apparatus include the sampling of the transmitted waveform in order to perform a pulse by pulse calibration and the selection pulse length and PRF. Besides the obviously advantage in terms of computational power, one of the benefit expected from the new processor relies on the availability of a developmental environment, based on the C programming language, since the scarce maintainability of the previously adopted SP20 processor was an obstacle to RSP software upgrading. Planned activities at the Tor Vergata site include both observations of rainfall events in the urban area of Rome and Central Appennines and application of calibration techniques based on multiparameter measurements. Further information and data for dissemination, will be available on the web site of the radar meteorology group of ISAC (radar1.ifa.rm.cnr.it).

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