Rainfall mapping in complex orography from C-band radar at Mt. Midia in Central Italy: data synergy and adaptive algorithms

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1 Introduction

The topography of the Italian peninsula is highly mountainous and characterized by relatively small catchments and river basins (Marzano et al., 2004). In such conditions, rainfall monitoring must be performed by exploiting all sources of data: raingauge networks, satellite radiometers and ground-based weather radars. Each source is needed to have a detailed picture of the rain field at ground with a fairly accurate spatial texture and resolution.

Operating a meteorological radar is generally a challenging task when in presence of a significant beam blockage as in complex orography (Delrieu et al., 1999). Apart from enhanced ground clutter, mountainous obstructions of the radar beam can significantly reduce the radar visibility and, thus, its monitoring capabilities (Sauvageot., 1992). Indeed, this blockage can be used as an information for constraining path-attenuation correction algorithms in severe weather conditions (Serrar et al., 2000).

In this work, we have investigated the exploitation of radar data in a mountainous region such as Central Italy. De-cluttering and beam-blockage mapping techniques, based on a decision-tree combination of Doppler and static clear-air maps, have been used to derive the clutter maps in complex orography. A study on the path attenuation correction techniques has been also carried out and discussed. The main goal is to exploit the mountain radar returns to estimate the rain path integrated attenuation (PIA) along suitable rays at the lowest elevation angles (Serrar et al., 2000). A class of constrained algorithms has been considered and evaluated including the final value and the attenuation-adjustment. A recent case study on an orographic rain event has been analyzed in detail showing the rain field as estimated from several data sources.

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2 C-band radar at Mt. Midia

The orography of Central Italy is highly mountainous and its climatology is such that there is a predominance of low-to-moderate rainfall, having stratiform nature with high temporal persistence. Embedded convective rain may be also present mainly due to orographic effects (Marzano et al., 2004). During 2005 a new project for installing a C-band weather radar in Central Italy has been successfully accomplished. The goal was to replace an existing single-polarized radar, located in a valley near L'Aquila (Italy) and described by Marzano et al. (2004), into a new site at M. Midia near Tagliacozzo (L'Aquila, Italy) at the border between the Abruzzo and Lazio regions in Central Italy.

The project, sponsored by the Italian Civil Protection Dept. (DPC), has been a synergic work, coordinated by the research center CETEMPS (L'Aquila, Italy). It included both regional authorities (Functional Center of the Abruzzo Region) and Italian companies (Telespazio, Rome, Italy;

Icarus, Rome, Italy; Eldes, Florence, Italy). The weather radar antenna with a radome dome has been installed at the top of a telecommunication tower of 50-m height, as seen in Fig. 1, by using a special elicopter of DPC. An *ad hoc* elliptical wave-guide with very low insertion loss has been installed to connect the ground shelter to the radar antenna. The radar tower is close to other two 30-m towers located within the site. Mt. Midia top height is at 1760 m and has a unique visibility over more than 300° azimuthal sector at 1° elevation angle covering most Central Italy, including the Abruzzo inland and the urban area of Rome (see Fig. 2).

Fig. 1. Radar tower of 50-m height at Mt. Midia in Central Italy.

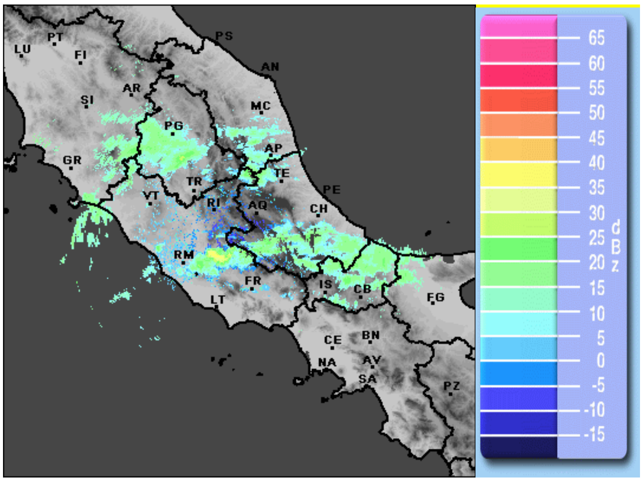

Fig. 2. PPI map at 2° elevation acquired from Mt. Midia C-band radar, on March 19, 2006 at 14:45 Local Mean Time (LMT).

The horizontally-polarized C-band radar, manufactured by Enterprise Inc. (USA), has a radome-covered parabolic antenna of 2.44-m diameter with 1.6° half-power beamwidth and 40-dB directivity. The magnetron peak-power is 250 kW at 5.6 GHz with a pulse repetition frequency (PRF) of 250 Hz (i.e., *intensity* mode with a pulse width of 1.98 μs) and 787, 885 and 1180 Hz (i.e., *velocity* mode with unfolding option and a pulse width of 0.75 μs). The receiver sensitivity is –110 dBm. The maximum range is 480 km and 120 km for the intensity and velocity mode, respectively. During the acquisition mode, a uniform angular resolution of 1° for both elevation (up to 4°) and azimuth angles is maintained constant without changing the pulse duration. A self-contained software, named EDGE®, is used to remotely operate and archive radar data. Volumetric radar data are routinely collected every 15 minutes and transmitted, through a microwave link, at the Fucino gateway station and then to the Radar centre in L'Aquila. As an example, Fig. 2 shows a case study, related to a rainfall event occurred in Abruzzo region during March 2006, which will be used to illustrate in detail the data post-processing technique. The figure shows a Plan Position Indicator (PPI) map acquired by the C-band radar at a range resolution of 500 m after de-cluttering. A continuous acquisition is routinely carried out using a 0.5°x1° azimuth-elevation angular resolution such that a single radar volume is completed in about 5 minutes.

3 Rain path attenuation correction techniques

As already mentioned, we have employed in this work a constrained algorithm to reconstruct the equivalent reflectivity along the range. As it will be clearer later on, we have used a mountain-return technique (MRT) in order to determine the two-way PIA along given directions (Serrar et al., 2000). Indeed, the MRT is a special case of a more general class of path-attenuation correction algorithms.

The considered path attenuation correction algorithms are briefly summarized here. We will refer to co-polar reflectivity Z_{hh} [$mm^6 m^{-3}$]. Measured co-polar reflectivity Z_{hhm} is related to equivalent reflectivity Z_{hh} and specific attenuation A_{hh} by (1). If r_N is the farthest range bin (i.e., edge of either the rain-cell), the co-polar path attenuation factor L_{hh} can be evaluated from PIA by:

$$L_{hh}=\frac{Z_{hhm}(r_N)}{Z_{hh}(r_N)}=e^{-0.46\int_{r_0}^{r_N}A_{hh}(r')dr'}=10^{-0.1\cdot 2\cdot PIA_{hh}(r_0,r_N)} \qquad (1)$$

Following Iguchi and Meneghini (1994) and assuming a power-law relation between specific attenuation A_{hh} [dB/km] and co-polar reflectivity Z_{hh}:

$$A_{hh}(r)=a[Z_{hh}(r)]^b \qquad (2)$$

with a=0.19·10^{-4} and b=0.826 at C band for temperatures between 0 and 40 °C, the *attenuation-adjustment* (AA) solution to (1), is given by (Marzano et al., 2003):

$$\hat{Z}_{hh}^{(AA)}(r)=\frac{Z_{hhm}(r)\left[I_{hh}(r_0,r_N)\right]^{1/b}}{\left[I_{hh}(r_0,r_N)-\left(1-L_{hh}{}^{b}\right)I_{hh}(r_0,r)\right]^{1/b}} \qquad (3)$$

where the integral I_{hh} is given by:

$$I_{hh}(r_0,r)=0.46b\int_{r_0}^{r}Z_{hhm}{}^{b}(r')dr' \qquad (4)$$

On the other hand, the *final-value* (FV) solution to (1) is given by:

$$\hat{Z}_{hh}^{(FV)}(r)=\frac{Z_{hhm}(r)}{\left\{L_{hh}{}^{b}+a\left[I_{hh}(r_0,r_N)-I_{hh}(r_0,r)\right]\right\}^{1/b}} \qquad (5)$$

It is worth noting that (3) and (4) can be transformed in estimated R along the radar range by means of empirical power relations such as:

$$R(r) = c[\hat{Z}_{hh}(r)]^{d} \tag{6}$$

where c=0.0157 and d=0.7042 have been deduced from Delrieu et al. (1999) for orographic rainfall.

4 Case study of March 19, 2006

We will here describe the analysis of the rainfall event observed on March 19, 2006 and the related data processing.

4.1 Event analysis from data synergy

The considered rainfall event took place on the morning of March 19 and developed though all the day moving from west to east, confirmed from the radar-derived Doppler winds between 10 and 15 m/s. A sample of data set available for the analysis of this event is shown in Figs. 3, 4 and 5.

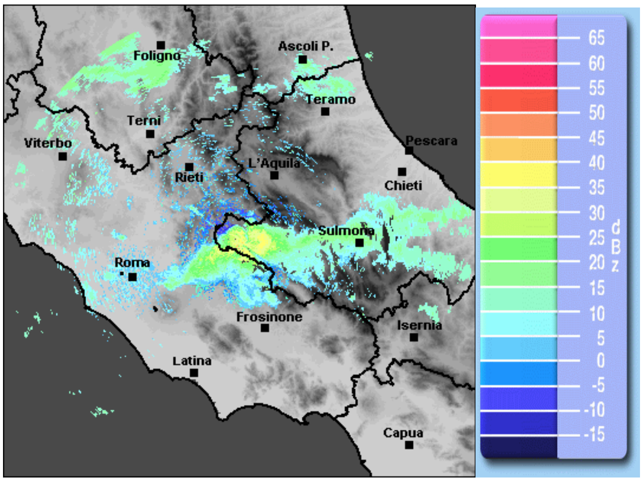

Fig. 3. PPI map at 2° elevation acquired from Mt. Midia C-band radar, on March 19, 2006 at 15:45 LMT.

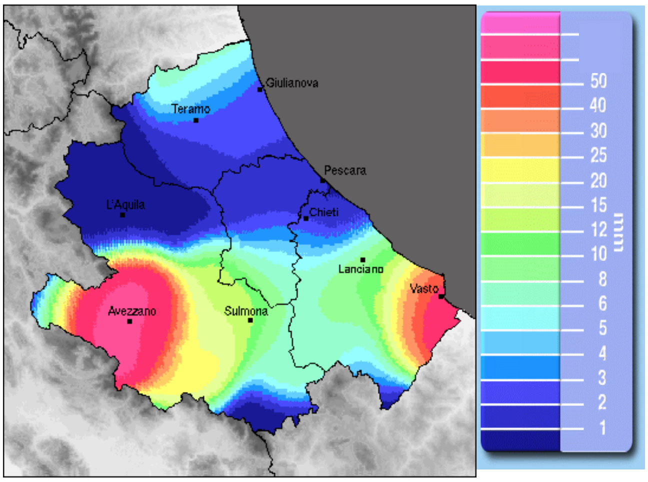

Fig. 4. Daily accumulated rainfall derived from the rain-gauge network on March. 19, 2006.

Fig. 3 shows the PPI map at 2° elevation acquired from Mt. Midia C-band radar, on March 19, 2006 at 15:45 Local Mean Time (LMT), that is after 1 hour with respect to Fig. 2. Fig. 4 shows the daily accumulated rainfall derived from the regional raingauge network after applying the modified Cressman spatial interpolation technique (Marzano et al., 2004). In both figures it is evident the precipitation in act which does not show convective cores, but is quite widespread. Fig. 5 shows the Meteosat-derived estimate of rain rate at 16:00 using a simple threshold infrared-channel algorithm, classified into low, medium and high intensity. From Figs 3, 4 and 5 it is worth mentioning the consistency of the rain field pattern observed at different spatial scales.

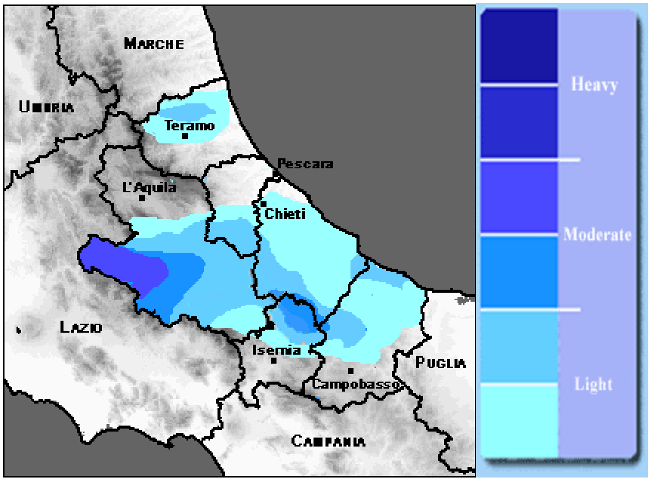

Fig. 5. Meteosat-derived estimate of rain rate on March 19, 2006 at 16:00 LMT.

4.2 Mountain clutter and path attenuation correction

The projected clutter map of the same area plotted in Figs. 2 and 3, derived from clear air scan in the days before March 19, 2006 is shown in Fig. 6. The latter clearly indicates where high power returns from mountains are present. These radar echoes can be used to estimate the two-way PIA. The black line is the 91°-azimuth direction where the Mt. Maiella return at about 77 km from radar has been selected.

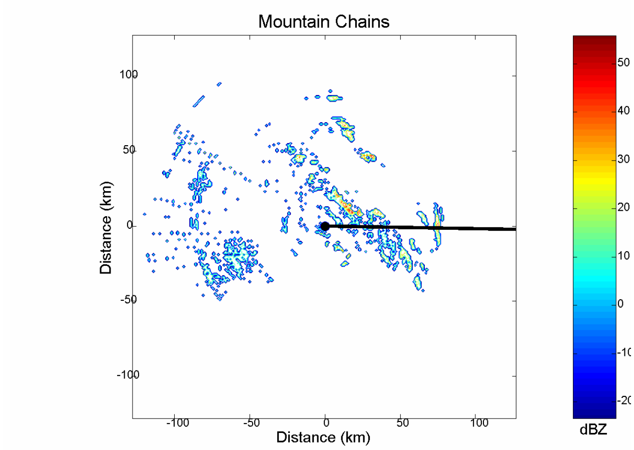

Fig. 6. PPI map at 2° elevation acquired from Mt. Midia C-band radar on a clear air day (March 18, 2006 at 16:00 LMT). The black line is the ray at 91° azimuth angle, analyzed in the next figures.

Fig. 7 shows the average horizontal profile along the azimuthal direction at 91° for an ensemble of no rainy events. Superimposed there is also the horizontal profile of the rainy event on March 19, 2006 along the same azimuth direction. The radar ray of Fig. 6 at 91° azimuth angle is represented in Fig. 8 in terms of both measured reflectivity range-profile and corrected reflectivity range-profile, using the FV method and the AA method.

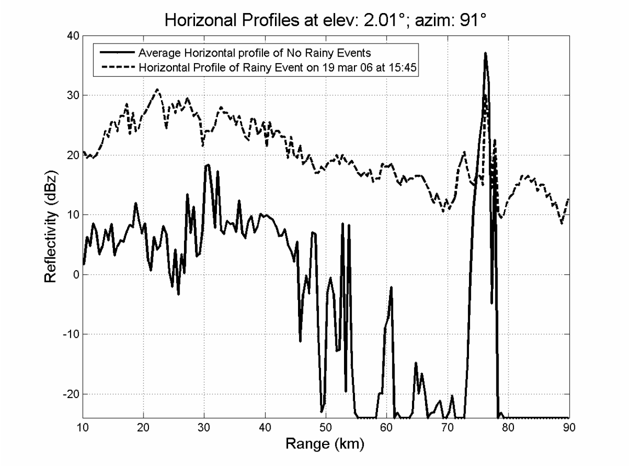

Fig. 7. Reflectivity range profile along the azimuth at 91° for an ensemble of no rainy events (solid line), superimposed to measured reflectivity profile of the rainy event on 19 March 2006 at 15:45.

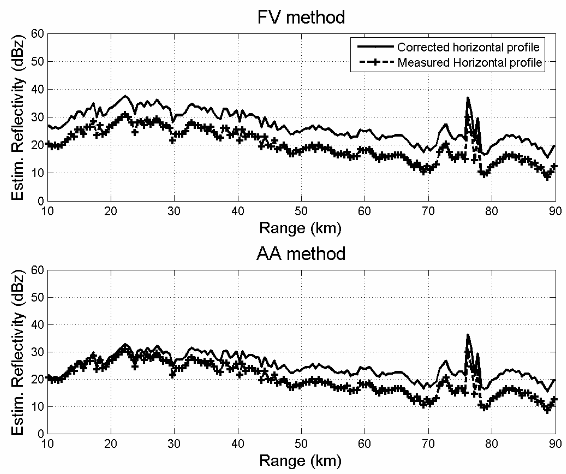

Fig. 8. Measured and corrected reflectivity range-profile along the ray of Fig. 6 using FV (top panel) and AA method (bottom panel).

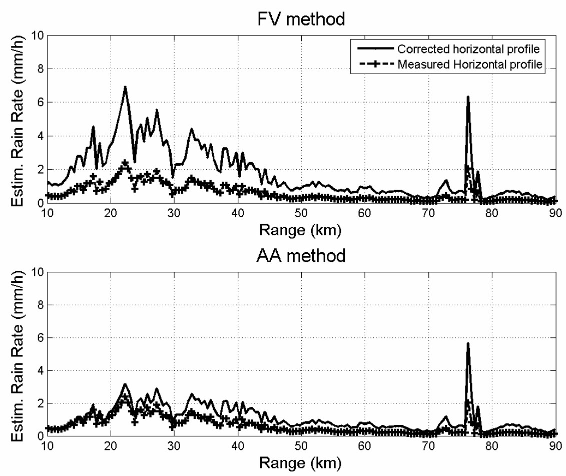

Fig. 9. Estimated rain-rate range-profile along the ray of Fig. 6 using FV method (top panel) and AA method (bottom panel).

The estimated two-way PIA is about 8 dB. The two methods do not give the same results as the act differently on the use of the PIA constraint information as obvious from (3) and (5). Using the algorithm in (6), Fig. 9 shows the estimated rain rate range-profile from measured reflectivity and from corrected reflectivity, plotted in Fig. 8, using the FV method and the AA method. As expected, the estimate rainrate differs if we consider the measured and the corrected radar reflectivity. We are unfortunately not able to evaluate which correction method is more accurate as we do not have available rain-gauge measurements along the ray direction.

5 Conclusions

In a complex orographic environment, like the Italian peninsula, a study on the data synergy and on path attenuation correction techniques has been carried out and discussed. The idea has been to exploit the various rain observations from space and ground and to use the mountain radar returns to estimate the path integrated attenuation along suitable rays, as proposed by Serrar et al. (2000). A class of constrained algorithms has been considered and described.

The verification of this concept has been presented with the comparison of mountain-derived PIAs within a case study of orographic rainfall on March 19, 2006. Results confirm that a synergic view of the rain field is essential for an operational interpretation and that the correction algorithms can be applied to correct path attenuation along given directions. Future work shall be devoted to a quantitative data fusion approach and validation of estimated rain fields at ground.

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