

Data processing in Weather Radars revisited

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1. Introduction

When digital data recording was introduced in the 70's, it was a common practice to be limited to one ray per 1 or 2 degrees (typically one ray per beam width), and one range cell per 1 or 2 km. With the advent of faster digitizers and more powerful computers little changed, maybe some improvement in range resolution up to 150 - 250 m (Fabry, 1997).

The number of elevation scans and the antenna rotation speed continue to be constraining dwell time. More elevation scans is always desired to have a better vertical resolution, but that means longer dwell time or faster antenna rotation, which in turn means less accuracy both in Z and V.

Today's computing power allows us to handle quite larger amounts of polar data than ever before, so some questions arose: Do we need to continue making polar cells by integrating in range and angle-time? Or can we make Cartesian products (say CAPPI for example) directly from high resolution polar data? If so, how high must be this resolution? How many elevation scans? How fast must we rotate antenna? Resolution in angle is constrained by the radar nature to one ray per pulse, but range resolution can go down to 15 m or less, is it useful? How do all these factors affect different products for different applications?

2. Storm model

To answer these questions we simulated a Reflectivity field based on statistical model of storms (Konrad, 1978), which imply linearly changing Reflectivity (in dBZ) with range. As a model, it was taken a cylinder of 12 km diameter, placed at 50 km from radar; center of cylinder is in 0° azimuth (North). This storm (cylinder) goes from 0 to 11 km in height (typical storm from Konrad, 1978).

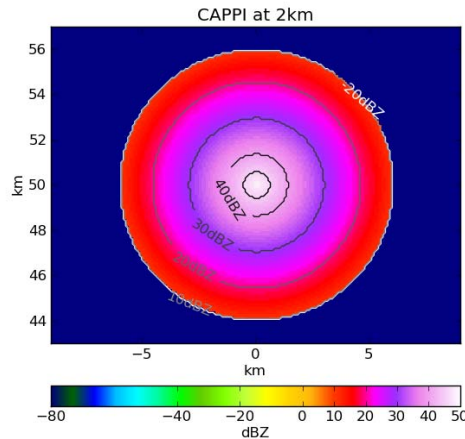


Fig. 1 Horizontal slice (2 km height), showing the original (mathematically generated) cylinder.

The radar acquisition process of this field of Reflectivity (using real beam width and real pulse length from our MRL-5 radar), is simulated taking into account beam smoothing (due to antenna rotation, Zawadzki, 1982) and range smoothing (due to receiver bandwidth, Doviak and Zrnica, 1979).

On the assumption that we know the spatial distribution of Z, the value estimated by detection integration can be obtained, as proposed by Zawadzki (1982), from:

$$Z_0 = \iiint G^2(\theta, \phi) W(S_r) Z(S_r, \theta, \phi) J(S_r, \phi) dS_r d\theta d\phi$$

Where:

S_r – Slant range from radar

$W(S_r)$ – range-dependent weight

$J(S_r, \phi)$ – Jacobian determinant to solve the integral in the more convenient “spherical” coordinates.

$G^2(\theta, \phi)$ – Gaussian beam function

Jacobian determinant:

$$J(S_r, \phi) = \frac{[R_e - S_r \sin(\phi)] \sin\left[\frac{2S_r \cos(\phi)}{\sqrt{R_e^2 + 2\sin(\phi)R_e S_r + S_r^2 - H_0^2}}\right]}{2\sqrt{R_e^2 + 2\sin(\phi)R_e S_r + S_r^2} [\sqrt{R_e^2 + 2\sin(\phi)R_e S_r + S_r^2 - H_0^2}]}$$

obtained from radar coordinate conversion equations, does not differ substantially from that obtained from spherical to Cartesian coordinate conversion equations.

In our case, the integral was solved numerically, establishing an integration region, wide enough to get weighting functions attenuated, for each sample.

In the simulation of the acquisition process, the following parameters were taken:

Parameter	Value
Radar Pulse Repetition Frequency (PRF), in Hz	250
Antenna Beam width, in °	1.5
Antenna rotation speed in azimuth, in r.p.m.	6
Analog to Digital Converter clock, in MHz	2
Range acquisition cell, in m	150

3. Coarse (usual) resolution case

Routinely, for Reflectivity measurements our MRL-5 radar acquires 360 angular sectors in one PPI (each sector 1.0°), and 450 cells in range (1.05 km each cell). Antenna is rotated at 6 rpm, PRF is 250 Hz. In the actual acquisition process, 7 range gates are integrated to form 1.05 km cell, and 7 rays are integrated to form 1° sector.

Taking this into account the simulated acquired data resolution was intentionally downgraded to make it comparable to that of the actual radar acquisition, by means of integrating 7 range gates, and 7 rays.

The question about can we obtain better resolution making products with lower Cartesian cell? is clearly answered in the following Fig. 2 a) and b).

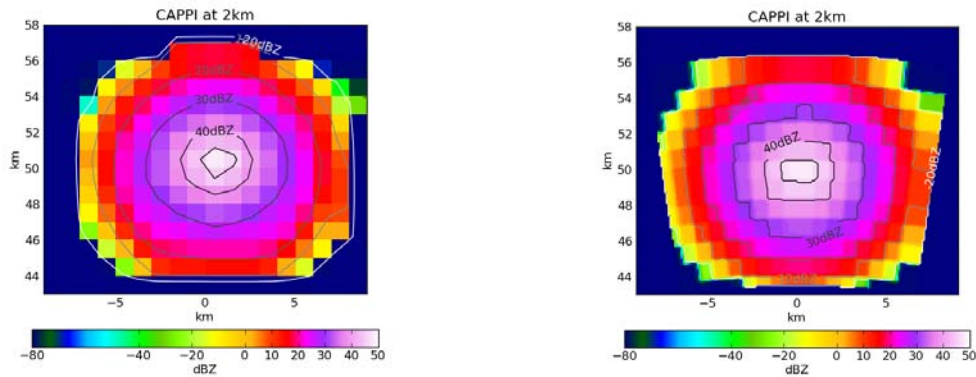


Fig 2. a) CAPPI at 2 km height, 1 km x 1 km.

b) CAPPI at 2 km height, 100 m x 100 m.

In Fig. 2 a), a conventional CAPPI at 2 km height is shown. This CAPPI was built making Cartesian cells as usual: 1 km x 1 km. In Fig. 2 b) it's shown an attempt to improve resolution making the CAPPI with Cartesian cells of 100 m x 100 m. As can be clearly seen, no further improvement was obtained. From a coarse raw data, just a coarse Cartesian product can be obtained. In both cases, the Adaptive Barnes fixed filter was used as described by Askelson, Aubagnac and Straka (2000). This algorithm was selected by its ability to take into account radar data properties, and to reduce variance of high resolution product. Parameters of filter used: $k_r=0.075 \text{ km}^2$; $k_\theta=k_\phi=0.155 \text{ deg}^2$.

4. High resolution case

We have now an increasingly amazing computing power available. So, why do we need to reduce data volume by means of making coarser polar cells? Why not to send all rays, and as shorter range gates as possible, directly to computer memory?

In that case, we would make Cartesian products directly from raw non-integrated in range and angle/time data. Can we improve resolution? Let's take a look.

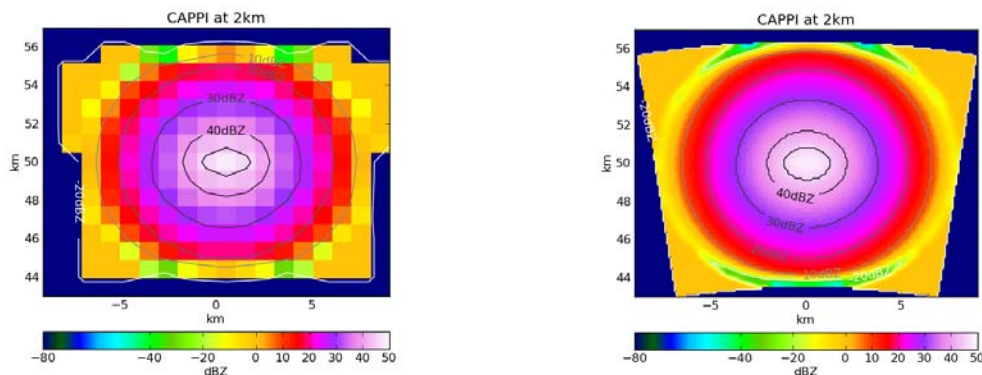


Fig 3. a) CAPPI at 2 km height, 1 km x 1 km.

b) CAPPI at 2 km height, 100 m x 100 m.

As can be seen, image on the right (Fig. 3 b)) shows better resolution. So, using acquired resolution instead of making coarser polar cells, do improve resolution. In both cases, again, the Adaptive Barnes fixed filter was used as described by Askelson, Aubagnac and Straka (2000).

One question can arise here. How about variance reduction? Classically, we used to reduce signal variance by means of integrating in range, and in angle/time a number of range gates and a number of rays. Further, the Polar to Cartesian filter again provided some variance reduction (Mohr and Vaughan, 1979). Here the filter parameters ($k_r=0.075 \text{ km}^2$; $k_\theta=k_\phi=0.155 \text{ deg}^2$) were chosen to get the same number of samples as in the actual coarse resolution case.

5. Concluding remarks

A mathematical model of Reflectivity field was obtained, generating a cylinder that can be placed anywhere in the radar umbrella, with Reflectivity varying linearly with range. The acquisition process was simulated taking into account radar range and beam smoothing.

The proposed method of generating products directly from raw data, shows better resolution, than conventional method of making products from cells integrated in range and angle/time.

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