2D WEATHER RADAR DATA SIMULATOR USING SPECIFIC REFLECTIVITY AND PHASE MEASUREMENTS FOR THE RAIN RATE ESTIMATION ALGORITHMS VALIDATION

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ABSTRACT

A modular simulator of 2D polarimetric rain radar measurements images has been developed based on the Rayleigh approximation. A dual physical-statistical model of the rain and a geometrical description of the rain downpours were considered in order to generate a set of the specific measurements for the rain rate estimation. Thus, the simulator produces images corresponding to the polarimetric radar data. It is a flexible tool that allows the user to choose among a variety of parameterizations of the rain process as well as the radar system involved in the measuring of the polarimetric variables. It has been illustrated on one example how the proposed simulator gives expected results from generated data. The simulator was also used as a laboratory to validate and compare some rain rate estimation algorithms. The obtained results go in harmony with known results in the literature. It is envisageable to implement additional modules in the simulator, such as the Mie and the T-Matrix approximations and the Doppler radial winds modules.

1. INTRODUCTION

With the increase of the world wide number of the meteorological natural catastrophes, the design of numerical weather prediction systems becomes crucial. This systems necessitates high-resolution data for both validation and assimilation. In this context, weather radar data are showing a great promise to achieve above gaols. Indeed, they are often available at spatial resolutions of less than one kilometer and at time steps of less than some minutes. Generally, validation of short-range rain rate estimation algorithms is based on precipitation totals measured sparsely and during a given period. In this way, errors of the estimation are not very meaningful given the instantaneous characteristics of the radar measurement. However, the advent of the high-resolution rain radar models, with a sophisticated microphysical parametrization, authorizes to make better evaluation of the rain rate estimation algorithms. In counterpart, this requires the development of radar simulators that emulate the behavior of the real radar systems.

In this work, we extended our 1D "Real-like" polarimetric radar data simulator presented in [1] to the 2D case. The proposed simulator is able to provide Real-like 2D cards of the rain radar measurements starting from an a priori knowledge of a 2D cards of the physical properties. It takes into account the spatial homogeneity characterizing the real weather downpours. The proposed simulator is highly modular, allowing the emulation of a wide variety of the rain physical process thanks to its great flexibility in fixing the starting physical properties of the rain and the geometrical configuration of the radar resolution cells.

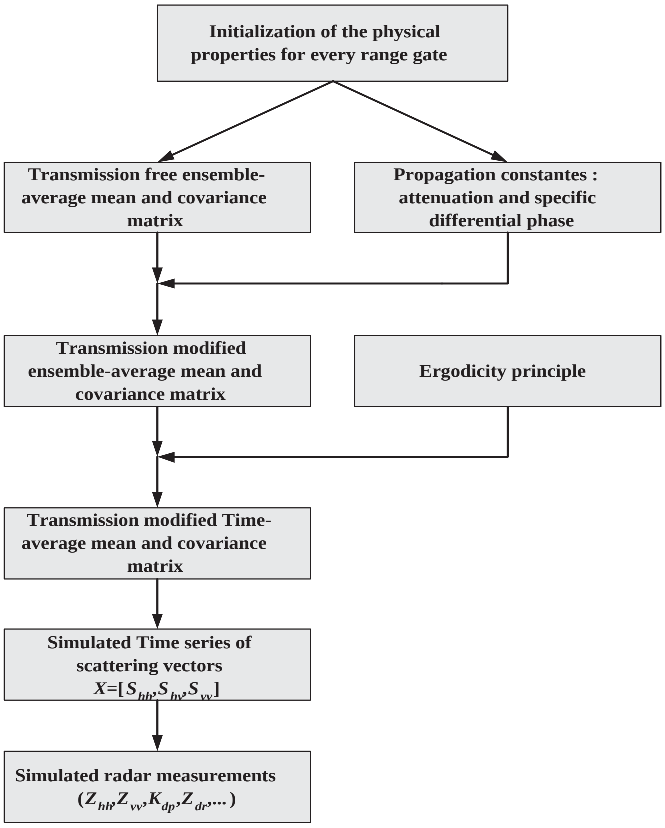

Figure 1: 1D Real-like radar Data simulator principal.

2. POLARIMETRIC DATA SIMULATION

The proposed Real-like polarimetric rain radar data generator is based on a dual approaches referring to both a physical and a statistical models of the rain target [2][3]. In the following we review briefly the 1D simulator proposed in [1] and than propose the 2D one.

2.1 The 1D Real like polarimetric radar data simulator

The retained physical model describes the rain drops as oblate spheroids [4], characterized by the equivolume sphere diameter D. It describes:

- the Drop Size Distribution (DSD)(e.g. the number of the particles that have the same equivolume diameter) by a

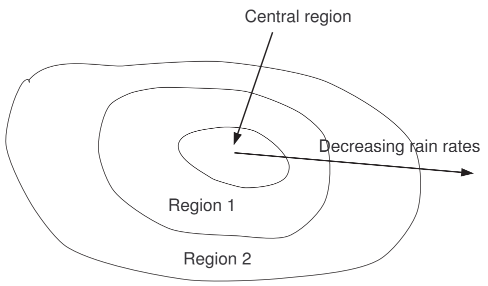

Figure 2: Homogenous regions for a rain downpour.

generalized three parameter Gamma distribution [4].

- the terminal velocity of the raindrops as proposed by Atlas and Ulbrich [2].

Using these parameters, analytical expression of the polarimetric covariance matrix elements can be computed in the Rayleigh approximation (Wavelength very large compared to the drop size). To make generated data more realistic, we proposed in [1] to use a statistical model for the rain radar returns. This model describes the scattering vector as a realization of a multivariate Gaussian distribution [5]. The ergodicity principal is invoked in order to link the two models. From, the generated time series of the covariance matrix the radar measurements (Reflectivities Z_{hh}, Z_{vv}, the differential reflectivity Z_{dr}, the propagation differential phase ϕ_{dp}...) can be deduced. The 1D simulator principle is summarized in the Fig.1.

2.2 The 2D Real like polarimetric radar data simulator

In this work, we propose an extension of the 1D simulator to the 2D case. This was possible throw considering the polar radar image as an $[M \times N]$ matrix. M designates the number of the angular resolution cells corresponding to a complete turn. N is the number of the radial resolution cells obtained by the rate of the radar coverage radius to the resolution cell depth. Following [6], the rain downpours consist generally of many homogenous regions for which the rain rates are decreasing from the central region to the regions around as illustrated in Fig.2.

The proposed simulator allows to fix the position of the central regions of the rain downpours. It allows also to fix the approximated size and shape for every rain region. Using these informations, a mask for the homogenous rain regions is generated. Starting from this mask, three $[M \times N]$ matrices corresponding to the parameters of the Gamma drop size distribution are generated. Thus, the mean and the variance values of the three parameter are fixed for every homogenous region. In order to guaranty a spatial homogeneity in the rain distribution (intra-region), the fixed spatial variances of the Gamma distribution parameters are small compared to the corresponding means. Once the previous steps are achieved, the 1D real-like polarimetric rain radar data simulator is applied line-by-line to the three representative matrices of the drop size distribution in order to generate matrices of the radar measurements. Finally, obtained matrices are displayed thanks to a specific module allowing to transform them into a 2D polar cards. The Diagram in Fig.3 summarizes the proposed 2D real like polarimetric rain radar simulator principle.

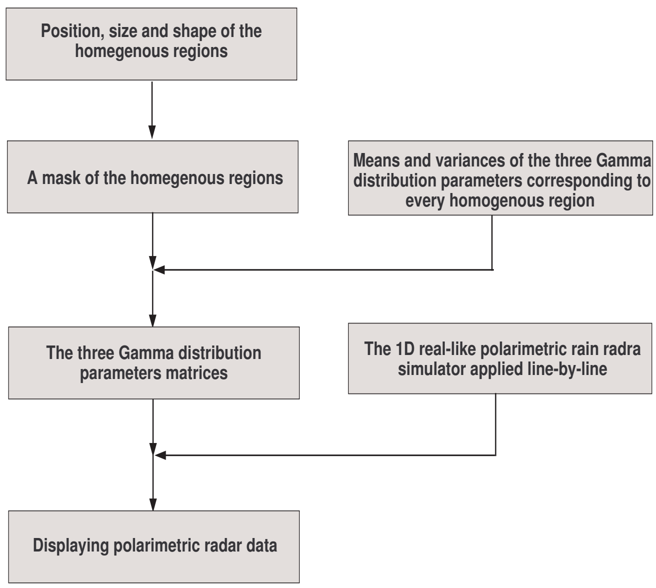

Figure 3: 2D Real-like radar Data simulator principal.

3. SIMULATION RESULTS

In order to evaluate the importance of the proposed simulator, a four-downpour radar image was generated. The position, shape and size of the downpours were choosen arbitrary. The Gamma distribution three parameters of the DSD are fixed in the ranges indicated in [7], which guarantee that the rain rate lies in the range of [0 mm h^{-1},400 mm h^{-1}]. The radial resolution is fixed to 100 m and the angular resolution is fixed to 1 deg. The radar coverage area is fixed to 20 Km. For every resolution cell, time series of 32 samples of the polarimetric covariance matrix were generated. Then, most relevant polarimetric radar measurements were deduced. In particular, the horizontal and vertical reflectivities Z_{hh} and Z_{vv} expressed both in dBz, the differential reflectivity Z_{dr} and the propagation differential phase shift ϕ_{dp} are shown in figure Fig.4. The obtained images go in harmony with real results obtained by working radars. Indeed, the values of the reflectivities are between 20 and 55 dBz for raining regions which is a very known result in the literature[8]. Also it is worthy to note the great correlation between the two reflectivities which confirm again the well working of the proposed simulator since the rain copolar correlation coefficient is usually more than 0.98 [8]. Moreover, from the Z_{dr} image we can remark that for light rain the Z_{dr} is arround 1 and it takes superior values for larger diameters. This is an expected results since drops with small diameters have an axis ratio around 1 and less values for larger drops.

4. VALIDATION OF THE RAIN RATE ESTIMATION ALGORITHMS

In the second step of the simulator validation, we have tested the rain rate estimation algorithms on generated data. More precisely we tested three algorithms: 1) R(Z,Z_{dr}) $= aZ^bZ_{dr}^c$ algorithm [9], the 2) R(K_{dp},Z_{dr}) $=$ $aK_{dp}^bZ_{dr}^c$,where K_{dp} is the specific differential phase obtained from ϕ_{dp} [10] and 3) R(Z,K_{dp},Z_{dr}) $= aZ^bK_{dp}^cZ_{dr}^d$ algorithms [11]. The physically computed rain rates as well as rain rates obtained by the different estimators are presented in Fig.5. Again, obtained results go in harmony with known results in the literature. Indeed, the $R(Z, Z_{dr})$ rain rate estimation algorithm gives best results for light rain rates. However, it results in great errors for heavy rain rates (central regions). On the contrary, the $R(K_{dp}, Z_{dr})$ algorithm gives important errors for estimating light rain rates and best results for heavy rain rates. This is can be explained by the important errors made in estimating the specific differential phase from ϕ_{dp}. Moreover, results from $R(Z, K_{dp}, Z_{dr})$ presented in [11] are confirmed here to be the optimal tradeoff. Indeed, it presents acceptable results for both light and heavy rain rates.

5. CONCLUSIONS

A modular simulator of 2D polarimetric rain radar measurements images has been developed based on the Rayleigh approximation. A dual physical-statistical model of the rain and a geometrical description of the rain downpours in order to generate a set of the specific measurements for the rain rate estimation. It has been illustrated on one example how the proposed simulator gives expected results from generated data. The simulator was also used as a laboratory to validate and compare some rain rate estimation algorithms. The obtained results go in harmony with known results in the literature. It is envisageable to implement additional modules in the simulator, such as the Mie and the T-Matrix approximations and the Doppler radial winds modules.

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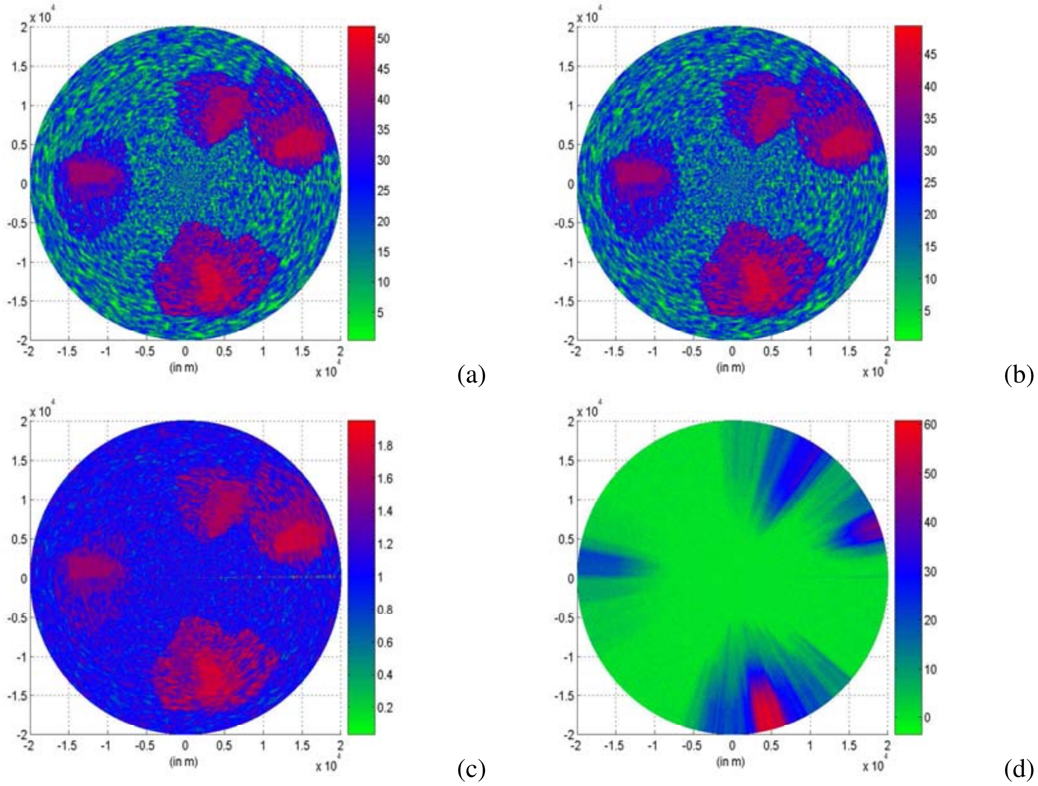

Figure 4: (a) Z_{hh} in dBz (b) Z_{vv} in dBz (c) Z_{dr} in dB(d) ϕ_{dp} in degree.

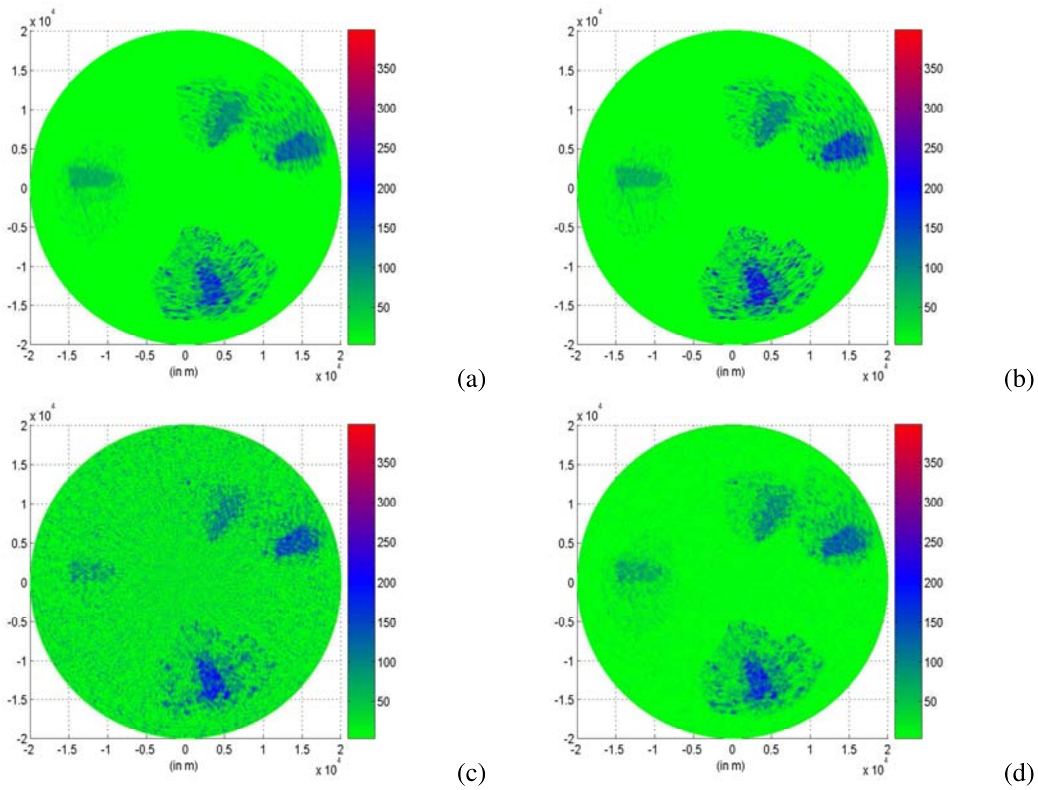

Figure 5: (a) Exact rain rate in mm h^{-1} (b) R(Z,Z$_{dr}$) in mm h^{-1} (c) R(K$_{dp}$,Z$_{dr}$) mm h^{-1} (d) R(Z,K$_{dp}$,Z$_{dr}$) in mm h^{-1}.