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A PRECIPITATION PROFILER SIMULATOR

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1. INTRODUCTION

A profiling radar simulator has been developed that replicates the hydrometeor scattering processes of vertically-pointing profilers. This simulator generates the in-phase (*I*) and quatrature (*Q*) voltages from a heterodyne Doppler radar receiver for every transmitted radar pulse. The simulator is constructed in modules so that the user can define all attributes of the radar (e.g., operating wavelength, antenna beamwidth) and the signal processing (e.g., Inter-pulse period, number of samples used in the coherent integration).

There are two main applications for this simulator. The first application visualizes *I* and *Q* voltages in order to better understand radar principles that are used by profiling radars. The second application simulates profiler observations in order to estimate profiler measurement errors that are needed to develop improved raindrop size distribution retrieval algorithms.

2. RADAR SIMULATOR OVERVIEW

The radar simulator architecture contains six modules as shown in Figure 1. The radar simulator is written in MATLAB to enable flexibility and expandability in each module. To facilitate the learning of radar principles and signal processing techniques, the radar simulator operates either in a Single Range Gate (SRG) mode or a Multi-Range Gate (MRG) mode. While in the SRG mode, the radar simulator processes the observations at only one range gate so that the user can focus on radar principles and signal processing techniques without the simulator performing unneeded computations at multiple range gates. The MRG mode is useful in investigating attenuation properties and vertical gradient issues in simulated profiles.

Each module shown in Figure 1 is briefly described in the following subsections.

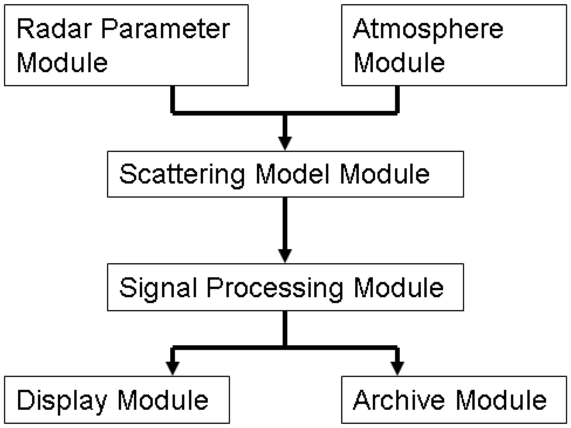

Figure 1. Flow diagram of the Precipitation Profiler Simulator.

2.1 Radar Parameter Module

The radar simulator replicates the operation of a pulsed radar system developed by the NOAA Aeronomy Laboratory (Carter et al. 1995). The user defines all attributes of the radar system in the Radar Parameter Module, including: operating frequency, transmitted power, antenna gain, antenna beamwidth, number of bits in the analog-to-digital converter, and mean system noise power. These radar parameters are hardware parameters that determine general characteristics of the radar system and usually don't change once the radar is installed for a field campaign.

2.2 Atmosphere Module

The user defines the atmospheric conditions by setting parameters in the Atmosphere Module. The atmosphere can be defined as a simple atmospheric slab with vertically constant parameters or a realistic atmosphere with altitude dependent parameters. The constant atmospheric slab is useful when operating in the SRG mode and vertical variability could be a distraction to the user. The user also defines the hydrometeor size distribution at all levels of the atmosphere. The user sets the following atmospheric condition parameters in the Atmosphere Module (either as vertically constant or as vertical profiles): air temperature, vertical wind speed spectrum, horizontal wind speed, humidity, liquid raindrop size distribution, frozen particle size distributions, and the terminal fall speed of the hydrometeors.

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2.3 Scattering Model Module

The Scattering Model Module replicates the physical processes of the electromagnetic wave propagating through the atmosphere and the backscattering of energy off of hydrometeors. This module also replicates the heterodyne receiver of a Doppler radar system. The outputs of this module are *I* and *Q* voltages for each transmitted pulse. Three different Scattering Model Modules have been developed; two for the SRG mode, and one for the MRG mode. Their differences are highlighted in the following sections.

2.3.1 Particle Target Model

The Particle Target Model tracks individual hydrometeors in the radar pulse volume during the dwell period. This model is computationally expensive because the *I* and *Q* voltages from each hydrometeor are estimated for every radar pulse. Then, the individual *I* and *Q* voltages for each radar pulse are accumulated to generate the final *I* and *Q* voltages estimated for each radar pulse. This model can estimate the *I* and *Q* voltages from a single particle to a thousand particles moving within the radar pulse volume. This module is useful in learning radar principles, the relationship between *I* and *Q* voltages, and the superposition of *I* and *Q* voltages.

2.3.2 Volume Target Model

The Volume Target Model estimates the *I* and *Q* voltages for each radar pulse by assuming a volume of scatters moving within the radar pulse volume. The user specifies the hydrometeor size distribution either using an analytical function (e.g. exponential or gamma function) or a discrete distribution. The module converts this DSD into an ideal reflectivity-weighted Doppler velocity power spectrum taking into account the user defined input parameters (e.g., antenna beamwidth, vertical air motion spectrum, and horizontal wind speed). The *I* and *Q* voltages for each radar pulse are estimated using the spectrum to time-series conversion described in Zrnic (1975). The conversion adds Gaussian noise and signal power fluctuations to the *I* and *Q* time-series data to simulate radar observations. This module incorporates our understanding of both volume scattering processes and noise statistics to replicate realistic *I* and *Q* voltages.

2.3.3 Profile of Multi-Volume Target Model

While the Volume Target Model determines the *I* and *Q* voltages for one radar pulse volume, the Profile of Multi-Volume Target Model concatenates individual Volume Target Models to replicate a profile of observations. This model is used during the Multiple Range Gate mode with individual range gates communicating with their neighbors to account for transmission losses due to atmospheric or hydrometeor absorption and scattering. The Profile of Multi-Volume Target Model is useful for simulating multiple range gates and the vertical structure of precipitation.

2.4 Signal Processing Module

One of the significant features of this profiler simulator is that the user can adjust the parameters of the Signal Processing Module and investigate the sensitivity and limitations of signal processing techniques used in profiler research. Since the *I* and *Q* voltages from each radar pulse are the input to the Signal Processing Module, all aspects of profiler signal processing are replicated including: coherent integration, Hanning windowing, FFT estimation, and incoherent integration. This module also estimates the noise level, the noise variance, and the moments of the reflectivity-weighted Doppler velocity power spectrum including: Signal-to-Noise ratio (SNR), mean Doppler velocity, and velocity variance. This module replicates all signal processing used in current profilers (Carter et al. 1995) and can be used to evaluate new signal processing techniques.

2.5 Display Module

In order to visualize the profiler simulations, the Display Module enables the *I* and *Q* voltages and Doppler velocity power spectra to be plotted. The user can also easily display the simulations off-line since the simulator is written in MATLAB.

2.6 Archive Module

The Archive Module saves individual simulations to develop data bases to investigate the statistics of profiler observations during the same atmospheric conditions.

3. EXAMPLES

Two examples of the simulator are presented. The first illustrates the simulator as an educational tool and the second illustrates how the simulator can be used to investigate measurement uncertainties.

3.1 Particle Target Model

In this example, the Particle Target Model is used to simulate the radar observations when three raindrops are falling within the radar pulse volume. While this example is not realistic, the resulting *I* and *Q* voltages are educational in understanding basic radar principles. Figure 2 shows the simulated accumulated *I* and *Q* voltages from the three rain drops. In this simulation, there is no Gaussian noise and no signal power variances so that the final voltages are the superposition of three different complex voltages. There are 770 *I* and *Q* scaled voltages shown in Figure 2 with each sample separated by the inter-pulse period of 130 microseconds.

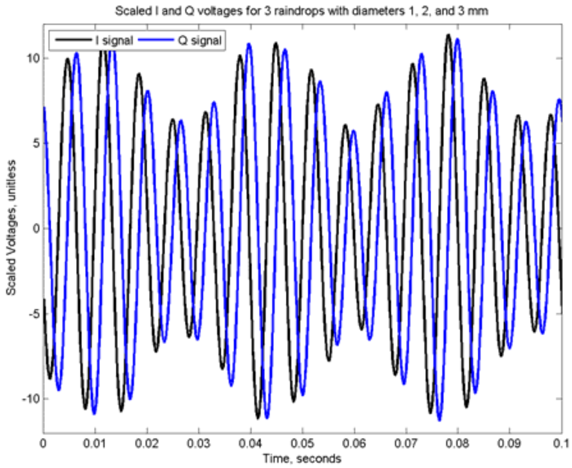

Figure 2. Scaled *I* and *Q* voltages for the simulation that contains three raindrops with diameters 1, 2, and 3 mm. The Inter-pulse period was 130 microseconds and the first 770 samples are shown. The *I* voltage leads the *Q* voltage indicating that the ensemble of targets are approaching the radar with positive Doppler velocity. The change in amplitude with time is due to the beating of the three complex sine waves.

3.2 *Volume Target Model*

While the Particle Target Model is useful to study radar scattering principles, the Volume Target Model realistically replicates profiler observations. As an example of investigating the measurement error of vertically-pointing profilers, the simulator was repeated fifty times using the same raindrop size distribution (DSD). The DSD for this example was defined to be a gamma function raindrop size distribution with reflectivity of 30 dBZ, median raindrop diameter, D_0, of 1.5 mm, and a shape parameter, μ, of 3.The solid line in Figure 3 shows the mean reflectivity-weighted Doppler velocity power spectra of the fifty simulations. Since the Gaussian noise and signal power variances were activated for these simulations, the vertical lines at each spectral bin correspond to the standard deviation of spectral power for the fifty different simulations.

For each simulation, the estimated spectrum was processed to estimate the reflectivity. The standard deviation of the reflectivity from the fifty simulations was 0.41 dBZ. This measurement error includes the errors associated with estimating the noise level and the SNR for each spectrum. There errors need to be included when estimating the measurement accuracy of vertically-pointing profiling radars.

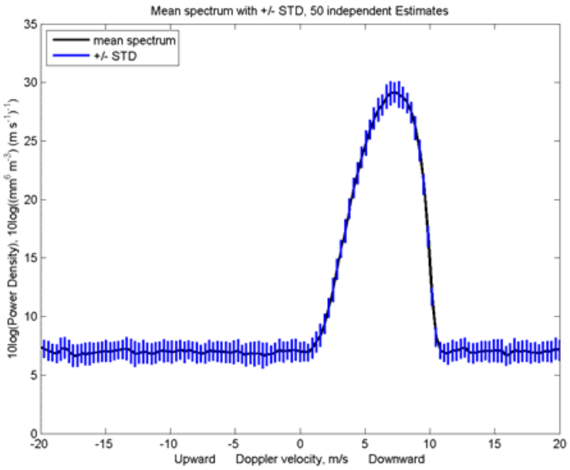

Figure 3. Mean reflectivity-weighted Doppler velocity power spectral density (black line) for 50 simulations. The input parameters were Z = 30 dBZ, D_0 = 1.5 mm, μ = 3, zero vertical air motion, and spectrum broadening of 0.25 m s^{-1}. Plus and minus one standard deviation at each Doppler velocity bin is show with the blue lines. The standard deviation of the reflectivity from the 50 simulations was 0.41 dBZ.

4. CONCLUDING REMARKS

A radar simulator to help describe radar principles and investigate measurement uncertainties has been developed. The current version of the simulator replicates the Rayleigh scattering associated with liquid raindrops. Modules are being constructed to include Rayleigh scattering from frozen particles and non-Rayleigh and Mie scattering processes associated with high frequency radars.

5. REFERENCES

Carter, D.A., K.S. Gage, W.L. Ecklund, W.M. Angevine, P.E. Johnston, A.C. Riddle, J. Wilson, and C.R. Williams, 1995: Developments in UHF lower tropospheric wind profiling at NOAA's Aeronomy Laboratory, *Radio Sci.*, **30**, 977-1002.

Zrnic, D.S., 1975: Simulations of weatherlike Doppler spectra and signals, *J. Appl. Meteor.*, **14**, 619-620.