

Simulations of Polarimetric Radar Signals Based on Numerical Weather Prediction Model Output

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Abstract

- Simulations of radar signals are important in understanding the performance of a radar system and its signal processing
- We present the added feature of generating radar signals for dual-polarization.
- Differential reflectivity, differential phase and cross correlation coefficient are estimated from radar signals.

Introduction

- Recently, Cheong et al. (2008) developed a weather radar simulator. This simulator is capable of generating realistic, three-dimensional, time series data over many range gate and azimuth angle. The simulator used thousands of scatters moving with the wind field produced from a high-resolution Advanced Regional Prediction System (ARPS) model (Xue et al. 2000).
- In this work, polarimetric capability is added to the radar simulator.
- Horizontal and vertical channel signals are simultaneously produced. Propagation effects of attenuation, differential attenuation and extra phase shift are included.
- To be more realistic, the model output for a mixed-phase microphysics is used and contributions from five species of hydrometeors i.e.: rain, snow, hail, rain-snow mixture and rain-hail mixture are accounted for.
- Polarimetric radar parameters such as differential reflectivity, differential phase and copolar cross correlation coefficient are estimated from the simulated signals.

Time series polarimetric Radar Simulator

The basic theory of the radar simulator is the Monte Carlo integration. Each sample of horizontal and vertical composite signal is a complex sum of the baseband signal from all the individual scatterers, which can be expressed mathematically as follows:

$$V_{h,v} = \sum_{n=1}^N A_n^{(j)} \exp[-j\phi_n^{(j)}] + N_{h,v}$$

$$\text{with } A_{h,v}(x, y, z) = \left(\frac{1}{r}\right) w_r w_a Z_{h,v}$$

$$\phi_n^{(j)} = 2 \int_0^{r_j} (k_0 + \Delta k_{h,v}) dr$$

where n is the total number of scatterers within the radar resolution volume. $A_{h,v}$ represents the amplitude. $\phi_n^{(j)}$ represents the phase of the n^{th} scatterer. N represents additive white Gaussian noise. $Z_{h,v}$ is the equivalent reflectivity factor of the individual scatterers. w_a and w_r are angular weight function and range weight function, respectively. The extra wave number $\Delta k_{h,v}$ is added the free-space propagation constant k to obtain the effective propagation constant of hydrometeor-filled medium. r_j is the distance from n^{th} scatterer to radar, where r_j is changing with time. Time series wind extracted from ARPS updates the location of the scatterers.

➢ Reflectivity factors:

$$Z_{(h,v)} = Z_{(h,v),r} + Z_{(h,v),rs} + Z_{(h,v),ds} + Z_{(h,v),rh} + Z_{(h,v),dh}$$

$$\text{with } Z_{(h,v)} = \frac{4\lambda^4}{\pi^4 |K_w|^2} \int n(D) (A |f_a|^2 + B |f_b|^2 + 2C |f_a||f_b|) dD$$

$$Z_{(v,s)} = \frac{4\lambda^4}{\pi^4 |K_w|^2} \int n(D) (B |f_a|^2 + A |f_b|^2 + 2C |f_a||f_b|) dD$$

r stands for rain; rs stands for rain-snow mixture, ds stands for dry snow, rh stands for rain-hail mixture and dh stands for dry hail.

Parameterization method:

$$Z_{h,r} = \frac{4\lambda^4 N_{0r}}{\pi^4 |K_w|^2} \Lambda_s^{-2(\beta_r+1)} \Gamma(2\beta_r+1) \cdot (A\alpha_r^2 + B\alpha_r^2 + 2C\alpha_r\alpha_{sb})$$

$$Z_{v,rs} = \frac{4\lambda^4 N_{0rs}}{\pi^4 |K_w|^2} \Lambda_s^{-2(\beta_{rs}+1)} \Gamma(2\beta_{rs}+1) \cdot (B\alpha_{rs}^2 + A\alpha_{rs}^2 + 2C\alpha_{rs}\alpha_{sb})$$

➢ Propagation phase:

$$\Delta k_{h,v} = \frac{180\lambda}{\pi} \int n(D) \text{ERe}(f_{a,b}) dD$$

Parameterization method:

$$\Delta k_{h,v} = \frac{180\lambda}{\pi} N_{0k} E\alpha_k \Lambda^{-2(\beta_k+1)} \Gamma(\beta_k+1)$$

For each scatterer, $\Delta k_{h,v}$ is integrated through the two way path from radar to scatterer to get phase part. Then, phase data is input into the process of generating time series radar data. Either of parameterization method or integration method can be chosen in this simulator.

3. Radar Signal Generation

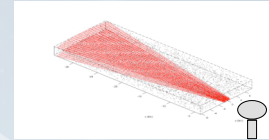


Fig. 1. Configuration of simulation domain and radar location.

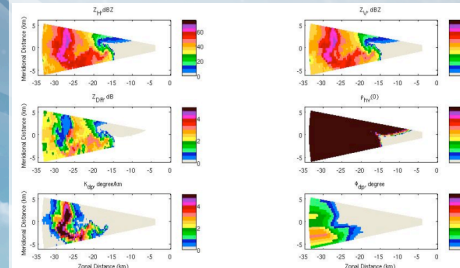


FIG.2. Directly obtained from ARPS data calculation. ARPS grid is sorted to radar beam.

- Average number of scatterers per volume: 30
- Frequency: 2.70e+09 Hz
- Dish radar at (0,0,0)
- PRT: 1.00e-03 s
- Pulse width: 1.57e-06 s
- azimuth beam width: 0.95 degree
- elevation beam width: 0.95 degree
- elevation: 0.50 deg
- azimuth extend: [-100.00 ... -81.00] degree
- azimuth step: 1.00 degree
- minimum range: 4000.00 m
- gate width: 235 m
- number of gates: 128
- number of pulse: 32

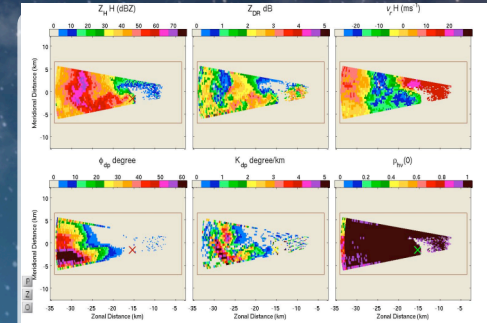


FIG.3. Polarimetric radar parameters estimated from the radar simulator generated time series data with noise. SNR=60dB

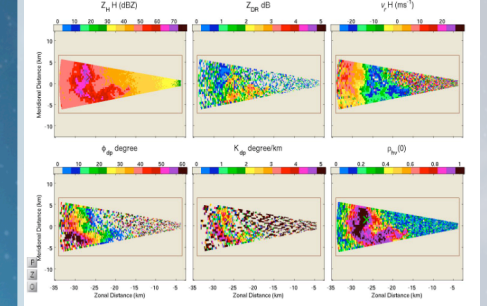


FIG.4. Polarimetric radar parameters estimated from the radar simulator generated time series data with noise. SNR=10dB

4. Conclusions

The estimated polarimetric parameters are shown in Fig. 4 for signal-to-noise ratio of 10 dB. While the reflectivity and ρ_{HV} signatures are preserved at the storm center. Polarimetric parameters of Z_{DR} and K_{DP} are degraded due to the added noise and sampling error of estimation. This shows that it is important to have a high SNR to produce high quality of polarimetric radar data. Advanced signal processing may be needed to improve the estimation.

By comparing the model-derived moments(Fig.2) with the time-series-estimated moments(Fig.3), it has been demonstrated the simulator performs properly.