ARM Radar Simulator: A Tool for comparison of modeled and observed clouds and precipitation at the ARM Climate Research Facilities

BROOKHAVEN NATIONAL LABORATORY

P. Kollias and E. Luke
Brookhaven National Laboratory

ARM Atmospheric Radiation Measurement

1. ARM Radar Simulator: Introduction

The Atmospheric Radiation Measurement (ARM) program has an excellent record in gathering data for the development and testing of models of atmospheric radiation transfer, properties of clouds, and the full cloud life cycle, with the ultimate goal of developing and validating new parameterizations for climate models. Toward this goal, we are developing a new tool, the ARM Radar Simulator (ARS), for direct comparison between modeled and observed clouds and precipitation at the ARM sites using existing and future ARM radar systems.

2. ARM Radar Simulator: Definition

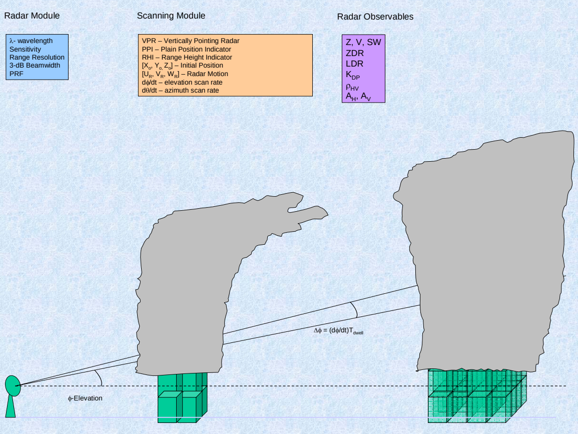
A software program capable of accurately emulating the interaction of the E/M waves transmitted by a radar with the hydrometeors in a radar resolution volume, and estimating the multi-parametric radar observables.

All technical radar characteristics (e.g., sampling strategy, beamwidth) that influence the radar measurements are included in the software.

Capable of simulating all radar frequencies, hardware specifications, and scanning strategies (VPR, PPI, RHI, airborne, space-borne).

Atmospheric state variables such as 3D wind field, water vapor and temperature, critical for the determination of the radar observables at a particular range and propagation effects are also incorporated in the software.

Simulates both Doppler and polarimetric radar observables. Future version will include Bragg scattering, insect scattering and melting layer radar signature.



3. ARM Radar Simulator: Purpose

Alleviate uncertainties related to the retrieval process, Because the forward model can be described much more accurately than the inversion process, which always involves certain assumptions.

Take full advantage of the information content of multi-parametric Doppler radar observations rather than a few retrieved parameters such as cloud boundaries and LWP.

Use as engineering/feasibility tool for the development of future ARM radar observing systems.

4. ARM Radar Simulator: Input

The simulator uses model-produced cloud and precipitation 3D scenes as input. Both bulk and bin microphysics schemes are acceptable.

Model Input (x,y,z):

U,V,W	: wind components
T	: temperature
P	: pressure
ρ_{air}	: air density
R	: water vapor mixing ratio
XWC	: x-hydrometeor type water content
TKE	: sub-grid turbulence intensity

The density ρ_x (g cm^{-3}) of the species is given by a general power-law relationship:

$$\rho_x(D) = \alpha \cdot D^\beta$$

Species	α (gcm^{-3})	β	D_{min} (cm)	DD (cm)	D_{max} (cm)	Bins
Cloud	1	0	0.0002	0.0001	0.0050	49
Rain	1	0	0.0200	0.0100	0.6000	59
Ice	0.015	-1	0.0020	0.0010	0.0500	49
Snow	0.015	-1	0.0500	0.0200	1.0000	48
Graupel	0.4	0	0.0200	0.0200	1.0000	50

Fall velocity of species $V_x(D)$ in (ms^{-1}) at surface conditions ρ_{air}(Height=0)=1.2kgm^{-3}

Cloud particles (D in cm): $V_c(D) = 3000 \cdot D^2$

Rain particles (D in cm): $V_r(D) = 9.2 \cdot (1 - \exp(-6.88 \cdot D^2 - 4.88 \cdot D))$

Ice crystals (D in cm): $V_i(D) = 2247 \cdot D$

Snow (D in cm): $V_s(D) = 40 \cdot D^{0.55} \exp(-125 \cdot D)$

Graupel (D in cm): $V_g(D) = 130 \cdot D^{0.7}$

Density correction for particle fall velocity aloft

$$V_x(z,D) = V_x(D) \cdot \left(\frac{\rho_{air}(0)}{\rho_{air}(z)}\right)^{0.5}$$

Particle size distribution function

$$N_x(D) = N_{0,x} D^{\mu_x} e^{-\Lambda_x D} \qquad \int_0^\infty D^p N(D) dD = N_{0,x} \frac{\Gamma(1+p+\mu_x)}{\Lambda_x^{(1+p+\mu_x)}}$$

Cloud: $N_T = 150$ cm^{-3}

Ice: $N_T = 0.01$ cm^{-3}

Rain: $N_0 = \left(\frac{N_1 - N_2}{2}\right) \cdot \tanh\left[\frac{(q_{r0} - q_r)}{4 \cdot q_{r0}}\right] + \frac{N_1 + N_2}{2}$

$N_1 = 20$ cm^{-4}, $N_2 = 0.02$ cm^{-4}, $q_{r0} = 10^{-4}$ KgKg^{-1}

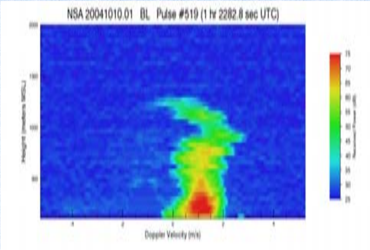
Snow: $N_0 = 2 \cdot 10^{-2} \cdot e^{-0.12T}$, T = temperature

Graupel: $N_0 = \max(10^{-4}, \min(\frac{10^{-4}}{q_g}, 10^{-2}))$

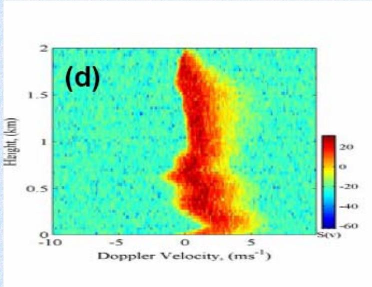
5. ARM Radar Simulator: Scattering

T-Matrix model is used to calculate the scattering properties of non-spherical particles.

Geometrical considerations: radar transmit polarization, radar sensitivity, radar sampling volume, radar elevation angle, radar dwell time, propagation effects etc.



Observed Doppler spectrum



Simulated Doppler spectrum

6. ARM Radar Simulator: Output

Profiling MMCR/WACR

Reflectivity	Z	size, concentration
Mean Doppler Velocity	V	size
Spectrum Width	σ	distribution width
Doppler spectrum	DS	DSD, phase
Linear Depolarization Ratio	LDR	particle melting
Circular Depolarization Ratio	CDR	non-sphericity

Scanning Cloud/Weather Radars

Reflectivity	Z	size, concentration
Mean Doppler Velocity	V	3-D wind field
Spectrum Width	σ	turbulence
Differential Reflectivity	ZDR	Shape, Orientation
Specific differential phase	K_{DP}	LWC, size
Linear Depolarization Ratio	LDR	Orientation, canting