Anonymous Referee #1
The manuscript describes CR-SIM, a radar and multi-instrument emulator that has a wide range of potential applications. CR-SIM is freely available to the scientific community and has the interfaces necessary to be broadly used (e.g., compatibility with major community models, physics schemes and data formats). Thus, this is an impactful study and provides an important overview of the tool and its applications.
The manuscript layout is excellent and easy to follow. Overall, the methods employed are sound and the analyses are well described. The only major comment I have is that the description of the radar emulator needs more specific details as described below. I also have some other minor and technical comments to consider.

Thank you very much for your comments and suggestions. Providing this valuable feedback has helped to improve the current manuscript. We have modified the manuscript, taking into account the referee's comments. The following contains our detailed responses to referee's comments, with our responses in plain type given underneath your original comments in bold type.

General comments:
1) Since the goal of this journal is to make the model reproducible, more equations, references, and is needed for the following items to achieve this:
a. How are the model PSDs transformed into radar variables? The authors acknowledge Dr. Vivekanandan's the Mueller Matrix code at the end, but I didn't see this cited or described in the text.

The radar observables are computed by integrating scattering properties over the discrete PSD using a constant size bin for each hydrometeor. The complex scattering amplitudes for equally spaced particle sizes are pre-computed and stored in the look-up tables using the Mishchenko's T-matrix code for single non-spherical particles at a fixed orientation. Using the calculated scattering amplitudes, we computed radar observables following Ryzhkov et al. (2011), accounting for an assumption of the orientation distribution which can be selected by the user. We described the information in section 2 in the revised manuscript. Because the equations of radar observables have been well described in Ryzhkov et al. (2011) and are not unique to CR-SIM, we decided to not add them in the manuscript. The method is fully described in the Section 4.4 and 4.5 in the CR-SIM User Guide (ftp://ftp.radar.bnl.gov/outgoing/moue/crsim/docs/crsim-UserGuide-v3.3.0.pdf).

To verify our computations of radar variables, we employed Dr. Vivekanandan's Mueller-matrix-based code from Vivekanandan et al. (1991). The figure below shows an example of a comparison of radar reflectivity for raindrops computed using the methods in CR-SIM and the Mueller-matrix-based code. The results show consistent values. Figures 4 and 5 in the CR-SIM User Guide compare all radar variables at 3 GHz and 9.5 GHz for raindrops. We revised the acknowledgement section to state how the Mueller-matrix-based code was used.

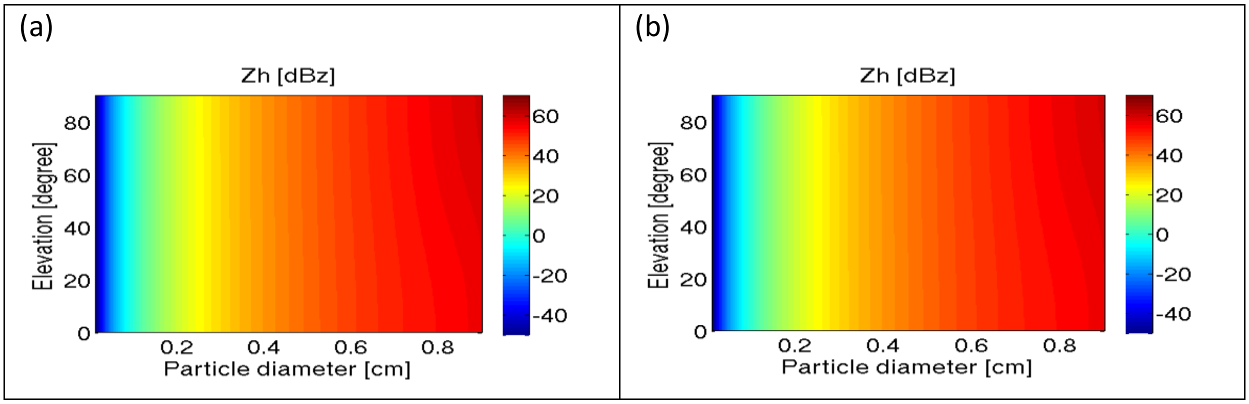

Figure: Comparison of Radar reflectivity at 3 GHz for raindrops as a function of elevation and particle size (diameter of an equi-volume sphere) computed by (a) method used in the CR-SIM based on Mishchenko's T-matrix code for a non-spherical particle at a fixed orientation and Ryzhkov's formulas for angular moments, and (b) the Mueller-matrix-based code from Vivekanandan et al. (1991).

b. How is the radar antenna pattern and pulse emulated? What are the range and antenna weighting patterns and are there different options?

We did not emulate the radar antenna pattern in CR-SIM. In the post-processing instrument model to convert grid data into radar polar coordinate data, we simply use a Gaussian function as a radar directivity function and average simulated radar observables within a range-gate bin with the gaussian weighting in the beam angle and range directions. We added the information to Section 2.3.

c. How are mixed phase hydrometeors treated in the calculation of scattering amplitudes, and how are the mixing ratios of these particles computed from pure liquid and pure ice hydrometeor classes in the models?

CR-SIM treats hydrometer categories for which mixing ratio (and/or number density) were predicted in the input cloud model using the selected microphysics scheme. At this stage, all ice hydrometeors (e.g., snow, ice, graupel, hail) are modeled as dielectrically dry spheroids i.e., assuming the dry growth of larger ice particles. Thus, the refractive index of dielectrically dry hydrometeors depends on relative mixture of air and solid ice. In other words, the refractive index depends on hydrometeor density and is computed using Maxwell Garnett (1904) mixing formula.

2) To give readers a sense of the computational requirements and burden for running a simulation, can you please describe what computing platforms were used for these simulations and what the simulation run times are?

We used a computer having 500-GB memory and 24 processors (Intel(R) Xeon(R) CPU E5-2670 v3 @ 2.30GHz) with 12 cores each for the simulations presented in the manuscript. The runtime depends on how many threads are used, simulation domain size, and the numbers of cloudy gridboxes. The following is an example of computer resources and runtime for the simulation of the MCS case in Fig. 1.

Domain size: 667 x 667 x 12
Number of threads used: 16
Runtime: 270 sec

Specific Comments:
Lines 73 – 87: A little deeper treatment of past radar simulators and where the authors' contribution fits is warranted. For example, aside from the applications, this will enable the reader to more clearly see what the strengths and weaknesses of the radar emulator are and how they compare to other emulator tools. For example, some radar emulators such as Snyder et al. (2017a,b) apply a radar forward simulator to the model grid cells whereas other simulators account for the radar observing geometry (e.g., beamwidth, range resolution). Other simulators emulate radar time series signals based on model turbulence whereas others do not. Finally, some simulators take into account complex electromagnetics of hydrometeors or other weather radar observed scatterers.
C. Capsoni, M. D'Amico, and R. Nebuloni, 2001: A multiparameter polarimetric radar simulator. J. Atmos. Ocean. Technol., 18, 1799–1809.
Caumont, O., V. Ducrocq, G. Delrieu, M. Gosset, J. Pinty, J. Parent du Châtelet, H. Andrieu, Y. Lemaître, and G. Scialom, 2006: A Radar Simulator for High-Resolution Nonhydrostatic Models. J. Atmos. Oceanic Technol., 23, 1049–1067, https://doi.org/10.1175/JTECH1905.1.
B. L. Cheong, R. D. Palmer, and M. Xue, 2008: A time series weather radar simulator based on high-resolution atmospheric models. J. Atmos. Ocean. Technol., 25, 230–243.
Jiang, Z., M.R. Kumjian, R.S. Schrom, I. Giammanco, T. Brown-Giammanco, H. Estes, R. Maiden, and A.J. Heymsfield, 2019: Comparisons of Electromagnetic Scattering Properties of Real Hailstones and Spheroids. J. Appl. Meteor. Climatol., 58, 93–112, https://doi.org/10.1175/JAMC-D-17-0344.1.

One of the features of using CR-SIM is it produces both radar and lidar observables for all the cloud resolving model grid boxes accounting for elevation angles relative to a radar location, similar to Snyder et al. (2017a,b), rather than other radar simulators that account for radar geometry characteristics such as beamwidth and radar range resolution to simulate scatters within the radar resolution volume (e.g., Capsoni et al, 2001; Caumont et al., 2006; Cheong et al., 2008). The radar sampling characteristics are accounted for in the post processing instrument model, as explained in the response to the referee's comment #1b. This feature facilitates the process of configuring any desirable observational setup with a varying number of profiling or scanning sensors.

The LUTs of scattering properties incorporated in the current CR-SIM were created using the T-matrix method where solid phase hydrometeors are represented as dielectrically dry oblate spheroids. These assumptions are rather simple compared to some other radar simulators which take into account complex electromagnetic scattering by mixed-phase hydrometeors or ice hydrometeors with possibly irregular shapes (e.g., Snyder et al., 2017a,b; Jiang et al., 2019). However, such complex electromagnetic scatters can be easily incorporated by adding LUTs of their scattering properties from different scattering calculation methods. In CR-SIM, a "scattering type" refers to each hydrometeor class for which the look-up tables were pre-built for a set of assumptions. Every hydrometeor specie present in the cloud model output must be assigned to the corresponding scattering type in the CR-SIM configuration setting. This approach enables addition of the new "scattering types" obtained using different and more complex scattering assumptions (e.g., Kneifel et al., 2017; Leinonen and Moisseev, 2015; Leinonen and Szyrmer, 2015; Lu et al., 2016) without any change to the code.

We added these descriptions in summary and section 2. Thank you for the suggestions and pointing out those papers.

Line 90: and spectrum width?

Yes. We added spectrum width to the sentence.

Line 105: What particle size spacing is used and what are the minimal and maximum sizes of particles simulated? The truncation can affect the resulting simulated measurements.

We set the minimum and maximum sizes and size spacing of simulated particles for each hydrometeor category within the bulk microphysics schemes, except for the P3 scheme. 'Particle size' here refers to the particle maximum dimension. We added the information to the revised manuscript.

Category	Minimum size [μm]	Maximum size [μm]	Size spacing [μm]
Cloud	1	250	1
Drizzle	1	250	1
Rain	100	9000	20
Ice	1	1496	5
Snow, aggregates	100	50000	100
Graupel	5	50005	100
Hail	5	50005	100

Lines 105 – 114: In general, I could follow the authors' description of the scattering properties and implement it into a simulator. However, there is no description of how mixed phase hydrometeors are treated. How is this accomplished?

Please see our response to the referee's comment 1c.

Line 197: Suggest "for convective cells" since multiple convective cells are evident in the image

Done.

Line 251: Should add a reference for the Morrison microphysics scheme

Done. We added Morrison et al. (2005).

Line 282: It isn't clear which simulation output is saved every 10 minutes (CR-SIM or WRF LES), or both.

The WRF LES output is saved every 10 minutes, and CR-SIM is run for each output file. We revised the sentence.

Lines 289 – 290: Is spatial or temporal sampling driving these major errors?

We think that both can be major sources of the errors. We revised the sentence to read "the limited spatial and/or temporal sampling is the major error source to consider when comparing the profiling measurement derived CFP with the domain-averaged WRF CFP."

Line 332: Should this say minimum detectable reflectivity Zmin, similar to a KASCR? Can you please provide the sensitivity of the simulated radar?

The minimum detectable reflectivity Z_{MIN} in the simulation is given by Eq. (4) with a constant C=-50 dBZ, which is similar to the Ka-band ARM scanning cloud radar (KaSACR). We revised the sentence.

Lines 342 – 343: How does this compare to the current CWRHI measurement interval?

The CFP estimation technique was applied to the Ka-band ARM scanning cloud radar at SGP. The product is available from the ARM Archive as an evaluation stage (https://iop.archive.arm.gov/arm-iop-file/0eval-data/wang/kasacradv3d3c/README.html). The CWRHI scans used in the product were provided at 20 sec intervals, which is a higher temporal resolution than that assumed in this study.

Lines 351 – 352: References needed for multi-Doppler error sources

We referred to Clark et al. (1980), Bousquet et al. (2008), and Potvin et al. (2012) in the revised manuscript.

Line 356: Which advection-correction technique? Please state and cite

Oue et al. (2019) used the advection-correction technique proposed by Shapiro et al. (2010) that allows for trajectories of multiple individual clouds, performs smooth grid-box-by-grid-box corrections of cloud locations, and takes into account changes in cloud shape with time by using PPI scans at two times. We added this description and reference to the revised manuscript.

Lines 364 – 366: While this study is examining a hypothetical scenario for VCPs, is the 60 elevation angle scenario practical for the listed update intervals of 2 and 5 minutes? This would require PPI scans every 2 or 5 seconds which is not possible with the XSAPR (but is with other X-band radar systems). Please elaborate on the technology limitation.

The referee is right. A volume scan with 60 elevations in less than 5 minutes is challenging for conventional scanning radars. The improvements required in the sampling strategy of the observing system (higher maximum elevation angle, higher density elevation angles and rapid VCP time period) can be accomplished using rapid scan radar systems such as the Doppler on

Wheels mobile radars (DOWs, Wurman, 2001) or even phased array radar systems (e.g. Kollias et al, 2018). We added this description to the last paragraph in section 3.4 in the revised manuscript.

Figure 1: The Doppler velocity and spectrum with colors are saturated in a large portion of the figures. Suggest a wider colorbar range.

Done.

Technical Corrections: Line 280: Suggest "highly heterogeneous" instead of "high heterogenous"

Done.

Line 283: Suggest "between 10-minute intervals"

Done.

Line 302: Suggest "Each panel shows that CFPs at a single site"

Done.

Line 695: Extra comma in the data "May, 20, 2011"

Done. We removed a comma after "May."

Figure 7 caption: units for cloud water mixing ratio should be g/kg

Done. Thank you for pointing the typo out.

Figure 9: Suggest "20-second output for 5 minutes" to be more clear in the Forward Model box

Done.