Responses to comments from Referee #1

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 all referee's suggestions. The following contains our detailed responses to your comments, with our responses in plain type given underneath your original comments in bold type.

The manuscript is very well written and understandable. It shows a sensitivity analysis of the multi radar Doppler variational vertical wind velocity retrieval technique based on a simulated convective event as a function of the number of radar involved and their position, radar scan strategy and time sampling. Although most of the technical aspects are described by words or using citations, perhaps the Authors could evaluate to describe some parts in more formal details e.g. by adding appendix for example to describe the coupling of WRF outputs and electromagnetic simulations of backscattering cross section used in the manuscript. I recommend for publication after some minor revisions.

Thank you for the referee for the appreciation. The radar simulator software and its user's guide are publicly available at https://you.stonybrook.edu/radar/research/radar-simulators/. The user's guide includes detailed descriptions about how the WRF output is coupled in the simulator and what electromagnetic scattering assumption is used. We would like to skip repeating the descriptions in the manuscript. Moreover, we are preparing to publish a separate paper to introduce the simulator and its applications.

Here we briefly describe about how the WRF output is coupled and the scattering assumption for the referee's reference.

The CR-SIM forward simulator is tailored to compute radar observables by integrating scattering properties over particle size distributions (PSDs) for each hydrometeor, on the basis of microphysics schemes incorporated in the weather model simulation. The environmental variables are obtained from the WRF model output variables and/or calculated using the obtained variables if necessary. Scattering properties of single particles are calculated using the T-matrix method and packaged as look-up tables (LUTs) in the simulator. The simulated 'idealized' observation variables are provided at each gridbox of the input model grid.

The LUTs compose the computed complex scattering amplitudes for equally spaced particle sizes using a T-matrix method developed by Mishchenko and Travis (1998) and Mishchenko (2000). The LUTs for each hydrometeor class corresponding to the model simulation data (e.g., liquid cloud, rain, snow, cloud, ice, graupel) are pre-built by setting particle phase, particle bulk density, and particle aspect ratio. For each hydrometeor class, the complex scattering amplitudes are pre-calculated for the total of 91 elevation angles from 0° to 90° with a spacing of 1°, different temperature ranges for liquid hydrometeors, different possibilities of particles densities for solid hydrometeors, and few different assumptions about particle aspect ratios.

Discussion paper
Main comments
1. Reflectivity weighted mean velocity: I am wondering if its calculation depends by the assumption made on the parameterization of the particle size

distribution within the numerical weather model used. For example, if you assume two different WRF run one using a microphysical schemes 1 and a second independent run using a microphysical schemes 2 which is different by the previous scheme and assume that both microphysical schemes are constrained by the same mixing ratios for a given WRF grid point. Would you obtain two different reflectivity weighted mean velocity for the two assumed microphysical schemes? Am I right? Although I understand that within an OSSE scheme is not necessary reproduce the true (unknown) Doppler velocity from WRF outputs for a single radar, I would suggest the Authors to add some comments in this aspect. Is it worth performing a sensitivity test with respect to the particle size distribution assumption to understand if your simulated velocity fields are consistent with what we expect during actual observations?

Parameterizations of the calculation of the reflectivity-weighted mean fall velocity (e.g., particle size distribution and V_f-D relationship) depend on the assumptions in the microphysical scheme used in the WRF simulation. The referee is right; if we use data from different WRF simulation coupled with a different microphysics scheme, the reflectivity-weighted mean fall velocity calculation follows the parameterizations of the microphysics scheme used. Therefore, the calculated reflectivity-weighted mean fall velocity could be different even if the simulated mixing ratio was same.

We agree with the referee that a sensitivity test to see an impact of particle size distribution assumption on the simulated Doppler velocity field is worthwhile. The present study, however, focused on uncertainties attributed to radar observation sampling in the retrieved wind field, rather than in an assessment of uncertainty of observed Doppler velocity due to microphysics by using the forward simulator. We would like to include the sensitivity test to a separate paper where we study impacts of hydrometeor particle assumptions, such as size distribution, terminal velocity, bulk density, and aspect ratio, on the simulated radar variables (reflectivity, Doppler velocity, and polarimetric variables). Thank you for the valuable suggestion.

We have tested a sensitivity of hydrometeor fall speed estimates to the vertical velocity retrieval. Please see a response to the referee #2's second comment.

2 In the advection correction section when you state: "The high temporal resolution WRF output allows us to evaluate the impact of advection and evolution of the cloud field during the time period needed to complete the radar network VCP." I am wondering if the 0.5 km horizontal resolution-WRF you are using resolves the processes involved within a time gap of 20 s or if 20s is just the time sampling used to write out the simulations. Later on when you state on page 15: "…the number of coherent updrafts structures show little sensitivity to the VCP time. This can be attributed to the fact that the number of updraft coherent structures does not change within the 5 min required to complete all sampling strategies". Can it be attributed to the fact that you are not resolving processes at very short time scales although you have an output at such scales?

The WRF simulation was performed with a time step of 2 seconds and output was saved every 20 seconds. We believe that the WRF simulation captured short time evolution well. Since we used outputs every 20 seconds in the analysis, the radar simulator analysis in this study might not capture the dissipation and formation of updraft cores within 20 seconds. Although it is possible that a few of the updraft cores dissipated or formed within 5 minutes, as we can track individual updraft cores using the

20-sec outputs (e.g. Fig. 3), the evolution of updraft cores was captured by the 20-sec outputs, and the number of updraft cores did not change significantly within 5 minutes.

3. It would be probably nice to add a table in the paper that summarize the results quantitatively (e.g. RMS).

We calculated root mean square errors (RMSEs) of UF, MF, and $\overline{w}$ profiles for the updraft thresholds 5 m s^{-1} and 10 m s^{-1} profiles above 2 km AGL for all experiments and added Table 3 to present those values in the revised manuscript.

Minor:

- page 5, lines 1-10: items 1-4: I am wondering if the gridding procedure (spherical to Cartesian) is introducing some errors and if the Authors took them into account. Which is the interpolation method used? Is interpolation in step 3 really needed or it is something done for facilitating gradients calculations?

Because we created radar polar coordinate datasets to emulate the radar sampling strategies, the gridding is mandatory before applying the 3DVAR wind retrieval used in this study. We interpolated the created radar polar coordinate data into the Cartesian grid using the Barnes distance-dependent weighting technique (Eq. 1 of the manuscript). But, for the 3FullGrid simulation, the gridding procedure was not applied because we used the original grid.

The referee is correct. The gridding process can also be an error source in the vertical velocity retrieval. This error can be included and seen when we compare the 3FullGrid simulation with the other simulations using radar VCPs. We discussed about this in the second paragraph of Section 3.1 in the revised manuscript. We used fixed settings for the gridding for all radar simulations except 3FullGrid in the manuscript, and therefore the differences between the radar simulation results (except 3FullGrid) may not include uncertainties attributed to the settings for gridding process.

- page 5 line 13 and hereafter: maybe is "equivalent radar reflectivity factor".

Done. We used a word "equivalent radar reflectivity factor" or "*Z*" in the revised manuscript.

- Eq. 1. It is not clear if you are applying the weights only in the horizontal plane or not. In other words, I was expecting that polar to Cartesian conversion was applied in 3D and not in 2D as Eq. 1 is suggesting. Please clarify.

We used this equation for both horizontal and vertical interpolations for gridding. We added the following sentence after the equation: "The equation was applied in both horizontal and vertical interpolations."

Pag 12, line 17, "The corresponding plots for the latest model output (12:19:40 UTC) used to forward simulate the highest elevations of the 2-min VCP are shown in Fig. 3 (middle row)." Middle row of figure 3 shows 12:19:00 and not 12:19:40.

We replaced the plots in the middle raw with those at 12:19:40 UTC and revised the last sentence of the Section 2.4.3 to read "The corresponding plots for the 13th model output (4 minutes after the first scan, 12:22:00 UTC) used to forward simulate the highest elevations of the 5-min VCP simulations is shown in Fig. 3 (bottom row)." Moreover, we changed a color scale of the reflectivity plots to clarify convective cores. Thank you for pointing this out.

Pag 12 Advection correction section. What happen when you intercept the bright band in the advection correction scheme?

The advection correction procedure has not been tested in the presence of a bright band. We can only speculate that there is nothing particular about a bright band that would cause special difficulties, because the advection correction technique does not use information that may be difficult to obtain information in bright bands (e.g., the detailed nature of the scatterers or the terminal velocities). If bright bands are horizontally inhomogeneous, the spatial variations should be able to be "tracked" with the advection correction technique as other reflectivity features are tracked. However, if there is a persistent largely homogeneous bright band covering the entire horizontal domain, the bright band might cause some problems.

In the present study, the radar simulator did not consider melting hydrometeors, thus a bright band was not distinguished in the simulated radar reflectivity fields. Therefore the advection correction was not affected by an issue that is caused by a presence of a bright band, if any.

Fig4. May be I would add a third and fourth row of panels showing the differences between the various scenarios and the original one.

We agree with the referee. However, because the horizontal grid box size is different between the WRF data (0.5 km) and the simulated retrieval data (0.25 km), we decided not to include the horizontal cross sections of the difference for the simulated retrieval from the WRF data. Instead, we added RMSEs of the profiles in Table 3 as suggested in the previous comment.

Figure 5. labels a, b,c, d, e are missing. Upper left panel: "2 min" is missing for the dark grey line.

Done.