Responses to comments from Referee #2

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.

General comment
The paper presents a sensitivity study aiming to address the error sources that affect the X-band Doppler radar-based retrieval techniques of vertical air motion. The main added-value of this work just lies in the comprehensive discussion of the limitations of such techniques. The paper productively contributes to add and extend the current research literature on this topic and can be accepted after some minor revisions.

Thank you for the referee's appreciation for the study.

Specific questions/issues
In my opinion, this study has one main limitation that needs to be considered and discussed. Such issue deals with the estimation of hydrometeors fall velocity (Vf). The authors state (Page 9, Lines 16-17) that Vf used in their work is the one predicted by WRF model simulation; therefore, they assume that no errors related to Vf are introduced in their experiment. In a more realistic scenario, the retrieval of wind field from radar Doppler measurements is strongly related to the variability of the terminal fall velocity of hydrometeors, which constitute a great source of uncertainty. I suggest to carry out, if possible, an additional experiment considering a scenario in which the hydrometeor fall speed is estimated from radar reflectivity measurements and not prescribed by WRF model or, at least, a more comprehensive discussion about the relationship between radar-estimated Vf and wind retrieval.

We agree with the referee that the hydrometeor fall velocity estimate can be a source of uncertainty. We have tested an impact of Vf estimate using reflectivity-based mass-fall velocity relationships proposed by Caya (2001) on the retrieved vertical velocity (presented below). The relationships generally tend to produce slower fall speeds than the reflectivity-weighted mean fall velocities calculated for the WRF simulation case. The retrieved vertical velocity areas from the simulation using the relationships were underestimated. For the referee's reference, we show a comparison between the simulated reflectivity-weighted fall velocity and a relationship for liquid from Caya (2001) and a comparison of the updraft fraction (UF) profiles with the WRF simulation and the 3FullGrid simulation using the relationship. However, the result does not necessarily mean that the relationships were incorrect or the retrieval was failure. It is hard to say whether the fall velocity estimate from these relationships or the hydrometeor fall velocity predicted by model simulation is more reliable. The present study focused on the uncertainties attributed to radar observation sampling, and we decided not to include the sensitivity test of the hydrometeor fall velocity estimate.
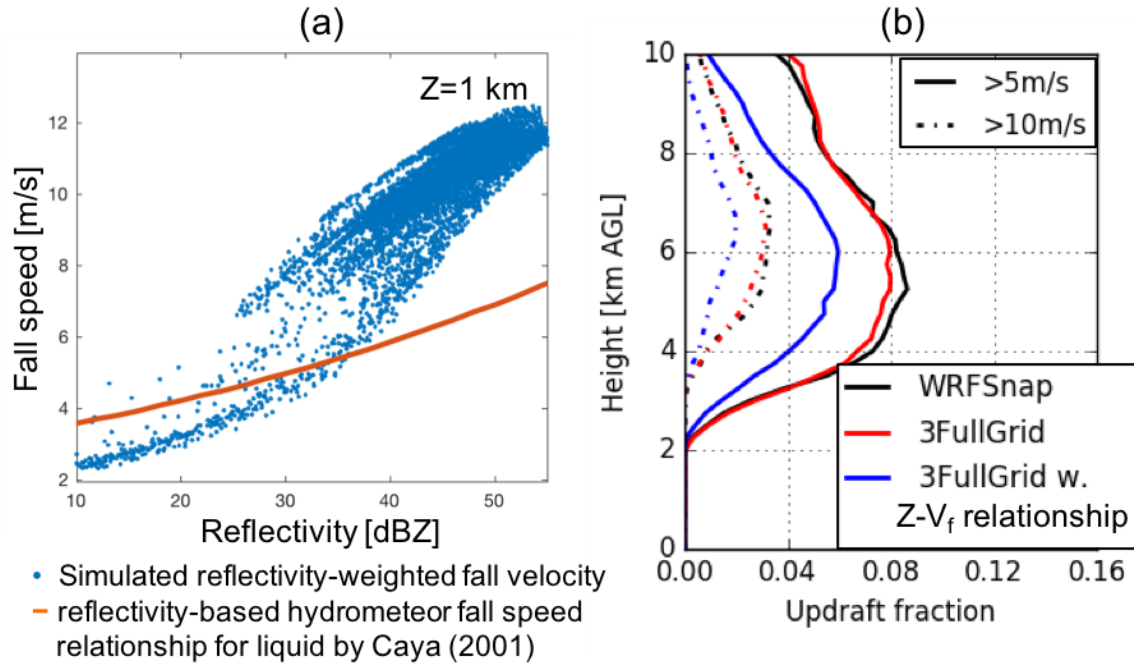
(a)

Z=1 km

- Simulated reflectivity-weighted fall velocity
- reflectivity-based hydrometeor fall speed relationship for liquid by Caya (2001)

(b)

Fig. R1: (a) Simulated reflectivity-weighted Vf versus reflectivity based on the Morrison 2-moment microphysics scheme at a height of 1 km (blue dots) and a reflectivity-based mass-fall velocity relationships for liquid proposed by Caya (2001) (orange line). (b) Vertical profiles of updraft fractions with different thresholds of 5 m s^{-1} (solid lines) and 10 m s^{-1} (dashed lines). In (b), Black lines represent the WRF snapshot at 12:18:00 UTC, red lines represent the 3FullGrid simulation, and blue lines also represents the 3FullGrid simulation, but used the hydrometeor fall velocity estimates proposed by Caya (2001). The reflectivity-based mass-fall velocity relationships for liquid and ice hydrometeors were parameterized:

$$V_f = 5.94 M^{0.125} \exp(\frac{h}{20}) \text{ for liquid}$$

$$V_f = 1.15 M^{0.083} \exp(\frac{h}{20}) \text{ for ice}$$

$$M = \exp(\frac{Z - 43.1}{7.6})$$

where h represents height in km, and Z represents reflectivity in a logarithmic scale.

Pag. 9, lines 13-18: the attenuation along the path is one of the main issue affecting the quality of X-band radar measurements. In my opinion, the authors should carry out a more in-depth sensitivity analysis concerning this issue and its possible impact on vertical wind retrieval.

The attenuation for hydrometeors can significantly impact the radar reflectivity measurements, but little impact on the Doppler velocity measurements. However, the attenuation in the reflectivity field can induce underestimations in the reflectivity-based hydrometeor fall velocity estimates. The underestimated hydrometeor fall velocity estimates could induce underestimation of the vertical velocity as shown in the response to the previous comment.

The abstract should be more concise. I suggest to summarize the results in a four or five lines, at most.

We itemized the results in the abstract and reduced the abstract.

Section 2, paragraph 2.1: please add some more details, for the convenience of the reader, about the MCS event considered in this work and about the study area.

We added short descriptions about the observed MCS and WRF-simulated MCS to the first paragraph of Section 2 and Section 2.1, respectively. For the observed MCS, we added: "This squall-line MCS was oriented in northeast-southwest direction extending for approximately 1000 km (Fan et al., 2017). The convective region had approximately 50 km width and trailed a distinct stratiform precipitation area when it passed through the ARM SGP site from 09:20 UTC to 11:40 UTC." For the WRF-simulated MCS, we added: "The simulated MCS comprised a convective precipitation region at the leading edge of the system and a stratiform precipitation trailed by the convective region, as similar as the observation. The MCS passed through the ARM SGP radar observation site approximately one hour later than the observation (at around 12:18 UTC), and a stronger convective precipitation region formed slightly (~20 km) to the north of the ARM SGP site."

Figure 2. Not very clear, in my opinion. Please avoid the use of jet colorbar in panel (c-f).

We changed the color scale for the nearest neighbor distance plots (c-f) in Fig. 2.

The conclusion section should be reduced, by summarizing the main results of the study.

We tried to reduce the amount of the itemized results by removing duplicated sentences.

The results of this study are presented only from a qualitatively perspective. Please introduce some common scores, such as the Root Mean Square Error, that quantitatively summarize the experiments performance.

We calculated root mean square errors (RMSEs) of UF, MF, and $\bar{w}$ 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.

Technical corrections
Pag. 2, lines 13 and 20: I suggest the use of the semicolon to improve the sentence structure.

Done. We rephrased the sentence at line 20 as "One drawback of profiling radar techniques is their limited sampling of individual storms and the lack of information on the temporal evolution of the convective dynamics and structure; the observational limitations, thus, make the use of the techniques in model evaluation challenging."

Pag. 2, line 23: please add "the" before "aforementioned".

Done.

Pag. 3, line 10 and Pag. 3, line 25: please add a comma before "especially".

Done.

Pag. 3, lines 11-12: I suggest to revise this sentence.

We revised this sentence to read "Clark et al. (1980) estimated errors attributed to cloud evolution in horizontal and vertical wind estimates from multiple Doppler radar measurements." Thank you for pointing this out.

Pag. 3, line 13: please add a comma before "by".

Done.

Pag. 3, line 16: please replace "are" with "have been".

Done.

Pag. 4, line 8: please add a comma before "that".

We separated this sentence into the following two: "It is possible that some of the errors are associated with radar volume coverage pattern strategy that does not satisfy the requirement for high spatiotemporal observations." and "This issue has been highlighted in recent studies with high-resolution CRM simulations of convective cloud properties (e.g., Morrison et al., 2015; Hernández-Deckers and Sherwood, 2016)."

Pag. 4, line 11: please replace "second" with "secondly".

Done.

Pag. 4, line 16: please add a comma after "to do so".

Done.

Pag. 4. line 19: please replace "we are investigating" with "we investigate".

Done.

Pag. 4, line 26: I suggest to use "consists in" instead of "is composed" and to remove "following steps".

Done.

Pag. 5, line 20: please substitute "retrieved" with "obtained" or "determined".

Thank you for the suggestion. We used "obtained" instead of "retrieved."

Pag. 6, lines 3-4: remove "in their study".

Done.

Pag. 6, lines 5-6: reformulate this sentence.

We rephrase this sentence as "This case has been analyzed for its dynamical and microphysical structures by many previous studies" and moved it to the first paragraph of Section 2.

Pag. 7, line 3: add a comma before "such".

Done.

Pag. 8, line 5: add a comma before "with".

Done.

Pag. 8, line 8: add a comma after "box".

Done.

Pag. 9, line 10: please add "carried out" before "in this study".

Done.

Pag. 13, lines 10-11: reformulate this sentence.

The advection correction procedure seeks to minimize a cost function that contains the frozen turbulence constraint and terms that confer spatial smoothness on the pattern-translation components. Appropriate values of the coefficient of the spatial smoothness terms depend on the horizontal grid spacing and a typical value of the tracked variable in the case. Based on preliminary tests (not shown), we deemed a coefficient of 300 dBZ^2 to be acceptable.

We added a following phrase to the previous paragraph:

"The advection correction procedure seeks to minimize a cost function that contains the frozen turbulence constraint and terms that confer spatial smoothness on the pattern-translation components."

and revised the sentence to read:

"A weighting coefficient of the spatial smoothness terms in the cost function coefficient depends on the analysis grid spacing and the structure of the field being advected. An appropriate value of the coefficient can be determined by running some sensitivity tests. Based on preliminary tests (not shown), we deemed a coefficient of 300 dBZ^2 to be acceptable."

Pag. 13, line 14 and line 15: add a comma after "fields" and before "field", respectively.

We added a comma after "fields" and "field", respectively. Thank you for the suggestion.

Pag. 14, line 13: add a comma before "using the original…".

Done.

Pag. 16, line 18: add a comma before "but".

Done.

Pag. 16, line 26: please revise "velocities lather than".

We revised it to read "updraft values."

Pag. 18, line 14: please remove the comma between "density" and "should".

Done.

Pag. 21, line 5: please add a comma after "VCP".

Done.

Pag. 21, line 9: add a comma after "…2016)".

To specify the previous studies, we avoided to add a comma there. Instead, we revised this sentence to read "The rapid evolution of the updraft structures simulated by the WRF are consistent with those from other modelling studies where the temporal evolution of the convective thermals can be significant over time periods larger than 2 min (e.g., Morrison et al., 2015; Hernández-Deckers and Sherwood, 2016)."

Pag. 21, line 27: please replace "were" with "was".

Done. Thank you for pointing this typo out.