Response to Reviewer # 1

We thank the reviewer for his review and valuable comments. The manuscript has been modified according to the suggestions proposed by the reviewer. The remainder is devoted to the specific response item-by-item of the reviewer's comments.

RC=Reviewer Comments
AR=Author response
TC=Text Changes

General Comments

The paper describes a MonteCarlo-based multiple scattering Doppler radar and lidar simulator. Though some of the described techniques replicate already published methods the work has its value because it offers a tool for both radars and lidars and represents an independent mean to evaluate results of other simulators developed by the scientific community. The simulator will have value especially with the launch of the EarthCARE mission. The scenarios proposed to demonstrate the capabilities are quite simplistic (e.g. only box clouds are used), but this is ok for presenting the potential applications of the tool.

Specific Comments

1) *There are no results shown for polarization. It would be great to see some results for the other Stokes parameters (not simply the intensity)*

We used the McRALI code to simulate profiles of the volume depolarization ratio measured by the CALIOP/CALIPSO lidar in our previous work (see Figs. 7-8, Alkasem et al., 2017). In the same work, we demonstrated that our simulation of the linear and circular depolarization profiles in a C1 cloud are in good agreement with the published data (see Appendix A.3, Alkasem et al., 2017). The later result was confirmed by other authors that cited our work (see, e.g., Sato et al., 2019; Wang et al., 2019).
We prefer to not present our new results on polarization in this work because they would make the paper under review too long. Those results will be the subject of a separated publication.

We modified the last sentence of the revised paper as follows:

"Real detailed cloud case studies and statistical analysis of representative fine-structure 3-D cloud field effects on lidar and radar observables, while taking into account the polarization of the light, will be the topic of future papers."

2) *I am a little bit surprised to see a mirror image from a Lambertian surface (but I may be radar-biased). Is this also present in lidar observations?*

To our knowledge, there exist no publications showing a mirror image in lidar observations from the atmosphere. Indeed, signal to noise ratio (SNR) of lidar is generally much lower than the SNR of radar. Thus, it seems to be practically impossible to observe a mirror image with a spaceborne lidar, contrary to a spaceborne radar (Battaglia et al., 2010).
The results presented in figure 3 should be considered as a numerical and theoretical exercise that demonstrates the McRALI capacities. The simulations were performed with a very high number of photon trajectories, so that the numerical noise of the McRALI simulator is low. Under these idealized simulations conditions, we show that McRALI is capable not only to

simulate lidar / radar systems with inclined sighting, by taking into account the properties of the Lambertian surface, but also the mirror images (as it is seen in certain radar observations). It should be noted that to make the mirror image appear in this simulation, we have imposed a maximum surface albedo equal to 1.
We add these sentences at the end of section 2.4 :

"Signal to noise ratio (SNR) of lidars is generally much lower than the SNR of radars. Thus, in practice it is impossible to observe a mirror image with a spaceborne lidar, contrary to a spaceborne radar. Results presented in fig.3 should be considered as a numerical and theoretical exercise that demonstrates the McRALI capacities. The simulations were performed with a very high number of photon trajectories, so that the numerical noise of the McRALI simulator is very low. Under these idealized simulations conditions, we show that McRALI is able to simulate lidar / radar systems with inclined sighting by taking into account the properties of the Lambertian surface, but also the mirror images (as it is seen in certain radar observations). It should be noted that to make the mirror image appear in this simulation, we have imposed a maximum surface albedo equal to 1".

3) *Line 16 in the intro: not true for the EC radar, no spectrum will be actually be provided.*

We thank the reviewer for this comment. In the revised paper, and according to suggestions of the second reviewer, we have changed the sentence "The Atmospheric LAser Doppler INstrument (ALADIN) of the ADM-Aeolus, the ATmospheric LIDar (ATLID) and the Cloud Profiling Radar (CPR) of the EarthCARE mission will provide spectrally resolved data." by :

The Atmospheric LAser Doppler INstrument (ALADIN) of the ADM-Aeolus provides spectrally resolved data. Indeed, the Mie receiver is a Fizeau spectrometer combined with a charge-coupled detector that measures the spectrum of the return around the emitted laser wavelength using 16 different frequency bins (Stoffelen et al., 2005; Reitebuch, 2018). The ATmospheric LIDar (ATLID) signals of the EarthCARE mission will be optically filtered in such a way that the atmospheric Mie and Rayleigh scattering contributions are separated and independently measured (Pereira do Carmo et al., 2019).The radar echoes of the Cloud Profiling Radar (CPR) of the EarthCARE mission will be input to autocovariance analysis by means of the pulse-pair processing technique for the estimation of the Doppler properties (Zrnic, 1977 , Kollias et al., 2013; Kollias et al., 2018). Note however that ATLID and CPR will not provide the spectrally resolved data.

4) *line 14 page 4: "receiver shape" which shape??*

In the revised paper, we have changed "… and account for emitter and receiver shape" by :

"… and account for emitter and receiver patterns of the lidar (or radar) system".

5) *Notation of Eq.8 is confusing, you are using first double and then single subscripts*

We agree with the reviewer. In the submitted paper, before Eq.8, the unit director vector defined between the scatterer i and i + 1, is written $k_{i,i+1}$. Then, after Eq.8, this same vector is written k_i. In the revised paper, we have changed $\boldsymbol{k_{i,i+1}}$ by $\widehat{\boldsymbol{k}}_{i,i+1}$ and we have added the definition of $\boldsymbol{k_i}$. in page 7, just after the Eq.8 :

"where $\boldsymbol{k_i}$ is the unit director vector defined between the scatterer i and i + 1".

6) *Fig4, bottom left panels: not sure why in the SS result there are values below cloud base. There should be none.*

In the submitted paper, the authors wanted to show in Fig4.c the values predicted by the theory using a vertical dotted line. But this way of doing things brings confusion since under the cloud, the theory does not foresee any value, as argued by the reviewer. In the revised paper we have removed these dotted lines and deleted the information in the legend and in the explanation of the figure.

7) *Page 7: "The frequency shift due to satellite motion is deliberately ignored..." well it is not clear to me then how you can simulate the Doppler broadening due to the satellite motion itself.*

In order to clarify how the Doppler broadening due to the satellite motion itself is simulated, we have modified this sentence (page 7) of the submitted paper "For example, at the second scattering event, the total frequency shift is computed as $\Delta f_{2;total} = \Delta f_1 + \Delta f'_2$, where $\Delta f'_2 = \frac{f_0}{c}\mathbf{v}_2.(\mathbf{k}_1 - \mathbf{k'}_2)$, $\mathbf{k'}_2$being the direction from the second scattering event to the detector (dotted blue line) which works with the local estimate method." by :

For example, at the second scattering event, the total frequency shift is computed as $\Delta f_{2;total} = \Delta f_1 + \Delta f'_2 + \Delta f'_{sat}$, where $\Delta f'_2 = \frac{f_0}{c}\boldsymbol{v}_2.(\boldsymbol{k}_1 - \boldsymbol{k'}_2)$, $\boldsymbol{k'}_2$being the direction from the second scattering event to the detector (dotted blue line) which works with the local estimate method and where $\Delta f'_{sat} = -\frac{f_0}{c}\boldsymbol{v}_{sat}.(\boldsymbol{k}_0 - \boldsymbol{k'}_2)$, $\boldsymbol{v}_{sat}$ being the satellite velocity.

8) *Formula 19: the formula is not accounting for other causes of spectral widths (for sure microphysics should be accounted for!). Add missing terms.*

In page 12 of the revised paper, we have changed "On Fig. 4c the MS and SS Doppler velocity spectral width profiles are drawn.Under SS approximation, the Doppler velocity spectral width is given by (Tanelli et al., 2002):

$$\sigma_{Dop}^2 = \sigma_{turb}^2 + \left(\frac{\rho_R v_{sat}}{2\sqrt{\ln{(2)}}}\right)^2 \qquad (19)$$

where v_{sat} is the satellite velocity relative to the ground and ρ_R is the Gaussian (3-dB) FOV half-angle" by :

On Fig. 4c the MS and SS Doppler velocity spectral width profiles are drawn.Under SS approximation, the Doppler velocity spectral width σ_{Dop} is given by (Kobayashi et al., 2003 ; Battaglia et al., 2013) $\sigma_{Dop}^2 = \sigma_{hydro}^2 + \sigma_{shear}^2 + \sigma_{turb}^2 + \sigma_{motion}^2$, where σ_{hydro} is due to the spread of the terminal fall velocities of hydrometeors of different size, σ_{shear} is the broadening due to the vertical shear of vertical wind, σ_{turb} is the broadening of the vertical wind due to turbulent motions in the atmosphere and σ_{motion} is the spread caused by the coupling between the platform motion and the vertical wind shears of the horizontal winds. For a Gaussian circular antenna pattern, assuming zero fall velocities of hydrometeors and no wind shear, σ_{Dop} is given by (Tanelli et al., 2002):

$$\sigma_{Dop}^2 = \sigma_{turb}^2 + \left(\frac{\rho_R v_{sat}}{2\sqrt{\ln(2)}}\right)^2 \quad (19)$$

where v_{sat} is the satellite velocity relative to the ground and ρ_R is the Gaussian (3-dB) FOV half-angle".

9) *Other minor comments: why not using the same color scheme for 65 and 650 microrad?*

In the revised paper, same colors are used for 65 and 650 microrad.

10) *Line 9 in the introduction: not clear why this line is there, out of context.*

In the revised paper, the sentence "CALIPSO and CloudSat missions were then extended for other 3 years (see, e.g., Vandemark et al., 2017)" is deleted.

11) *Introduce titles for the Appendices*

We have added titles in the revised paper.
Title of appendix A is "Definition of acronyms"
Title of appendix B is "Estimation of the PP bias of molecular, particulate and total ATB as a function of cloud coverage and multiple scattering intensity for the box cloud model"

References

K. Sato, H. Okamoto, and H. Ishimoto, "Modeling the depolarization of space-borne lidar signals," Opt. Express 27, A117-A132 (2019) https://doi.org/10.1364/OE.27.00A117

Z. Wang, S. Cui, Z. Zhang, J. Yang, H. Gao, F. Zhang, Theoretical extension of universal forward and backward Monte Carlo radiative transfer modeling for passive and active polarization observation simulations, Journal of Quantitative Spectroscopy and Radiative Transfer, 235, 2019, p. 81-94, https://doi.org/10.1016/j.jqsrt.2019.06.025.