Reply to Reviewer #1

The authors would like to thank Reviewer #1 for taking the time to read this manuscript and make helpful comments and suggestions. Almost all suggests were incorporated. Detailed replies are below, with *reviewer comments in blue italic Times New Roman font* and author replies in Arial regular font.

Reference to page and line numbers are for the TrackChange document with filename: Williams_kazr_hydro_mask_TrackChange_2021_0505v5.pdf

In their manuscript „Identifying Insects, Clouds, and Precipitation using Vertically Pointing Polarimetric Radar Doppler Velocity Spectra" Christopher Williams et al describe a combination of spectral texture and LDR to discriminate insects and hydrometeors in cloud radar Doppler spectra. The introduction of the texture and the combination with the frequently used spectral LDR are novel approaches. The topic fits well into the scope of Atmospheric Measurement Techniques and is recommended for publication after minor revisions. Especially the state-of-art review and theoretical basis (scattering properties of insects) can be expanded to provide a more comprehensive overview.

Detailed comments

1. P1L28: "All datasets and images are available […]". This statement is ambiguous. Are the quicklooks from the dataset available or the figures used in this manuscript?

There is a delay in making the images available. The lead author (CRW) knew that the daily netCDF data files, TIF images, and animations would be posted on the DOE ARM Archive, but he did not realize that the AMT supplemental material was limited to 50 MB and could not include animations. Paperwork has been submitted requesting DOE ARM archive data, images, and animations for 14 summer months (April-October 2018 and 2019). The netCDF files require 700 MB, the hourly TIF images require about 6 GB, and the profile-by-profile animations require about 5 GB of space. This manuscript will need to wait to be in final form until after DOE approves hosting the archive. In the interim, the netCDF data files, TIF images, and animations are on a Google Drive Folder: https://drive.google.com/drive/folders/1whhYC6op1nzMRg93FJYohjkFB6v1uLNU?usp=sharing

Text was changed to specify that data and images are available on the DOE ARM repository. See text near P1L29.

2. P2L16: "Due to their large power fluctuations […]". Are the power fluctuations the reason, why insects are detected in the power spectrum?

Thank you for asking about the power fluctuations because this sentence is not clear. It is not the power fluctuations in the time-domain that enables the insects to be detected in the power spectrum, it is the large change in power between velocity bins (i.e., delta power [dB] per delta velocity [m/s]) that distinguishes insects from clouds. This sentence was modified to improve clarity. See text near P2L16.

3. P2L26: "[…] of the operational ARSCL processing is identifying and removing insect clutter" More information on the state-of-art in ARSCL is needed. How is insect filtering currently done? What thresholds are used? How does the approach differ from other well established synergistic

retrievals, such as Cloudnet? Where are the gaps, this work tries to address? Please also consider showing the ARSCL insect flag for the case studies (Fig 3 and 4).
Text has been added briefly describing the insect filtering done in the ARSCL products and to address the gaps this work tries to address relative to prior work. Also, the ARSCL hydrometeor-only product was added to Fig. 4. See text near P2L24. See Fig. 4.

How does your algorithm differ from the MIRA-35 insect filtering, which also relies on spectral LDR (see description in Görsdorf et al. 2015 JAOT and the therein referenced Bauer-Pfundstein and Görsdorf 2007)?
Thank you for these references to the work of Görsdorf et al. and the work of Bauer-Pfundstein and Görsdorf. The main difference between the proposed method and these works is that the proposed method estimates the scattering process of each pixel in the profile before estimating the location of any peaks. The methods in Bauer-Pfundstein and Görsdorf (as well as Luke et al.) first identify significant peaks in the spectra and then classify each peak as a result of hydrometeor or insect scattering. Text was added to highlight the difference of these two approaches. See text near P4L2.

4. P4L24: "Figures and algorithm descriptions use the MD mode with retrievals for the GE mode available in the ARM data archive." Does that mean the algorithms for GE are used on the MD data or is this just an additional information that the other mode would be available as well? Please clarify. Does the presented algorithm perform equally well at the GE data?
When the manuscript was submitted, the plan was to run the same algorithms on the GE mode data and make the GE processed masks available on the ARM data archive. Due to other commitments since submitting this manuscript, the GE mode data has not been processed. Thus, the text was modified to state that the GE mode will be processed in the future and will eventually be available on the ARM archive. See text near P5L5.

5. P4 Eq. 1b and 2: Is the noise level independently estimated for SXPOL? Please provide the depolarization decoupling of the used system (integrated cross-polarization ratio, Myagkov et al. 2015 JAOT).
Yes, the noise level of every spectrum is estimated independently for both the CoPol and XPol channels. The KAZR handbook states that the cross polarization isolation is -27 dB. This information and reference to the KAZR handbook were added to the manuscript. See text near P5L8.

6. P4L26: "The KAZR 0.2° antenna beamwidth […]". Please give the diameter of the antenna. Is it covered by a radome?
More information on the KAZR antenna was added to the text. See text near P5L8.

7. P4L35: Please provide more technical information on the lidars. What are the wavelengths, what algorithms are used for cloud base detection?
More information on the Vaisala ceilometer was added to the text along with the ARM ceilometer handbook as a reference. See text P5L21.

8. P5 Table 1: What encoding sequence is used in the MD mode?
More information about the pulse duration, modulation, range resolution, and spacing between samples has been added to the main text and to Table 1. See text near P5L11. See table near P6L1.

9. Section 3 (P5L26): reads very phenomenological without addressing the underlying physics of the insect return. Is the observed texture characteristics caused by the point target scattering at individual insects? Such intermittent during the integration time of the Doppler spectrum and easily be identified by a time-frequency analysis of the IQ signal. If you have access to such low-level date it might be worth a look.
Yes, the high texture, or dP/dv across the power spectrum is caused by individual point targets having a fixed speed during the observation time of about 1.8 seconds. This is in contrast to the distribution of cloud particles moving at different velocities producing a smoother power spectrum. The introductory text to Section 3 was improved to highlight these two scattering processes at the beginning of the section (instead of having this key information hidden deep in the sub-sections.). See text near P6L28.

The authors have requested time-series data from the ARM archive to explore the time-evolution of the I & Q data. After looking at many spectra profiles, the insects tend to occur in two different scenarios: either isolated targets that appear in only one profile, or many targets with different velocities. It will be interesting to look at the data from an entomologist's prospective as the insects move through the radar resolution volume.

Are the sizes of insects expected at the SGP are similar to the wavelength or much smaller? How does the LDR signature of point targets depend on the pulse shape in the MD mode?
I (CRW) do not know if LDR changes with pulse shape. I would image that it not because the pulse is transmitted and the received on both CoPol and XPol channels which are decoded with the same compression filter. Changes in the pulse amplitude would affect both channels equally. Maybe this can be explored by comparing the LDR from the MD and GE modes because the GE mode is not using any frequency modulation. Regarding insect size, an insect with diameter smaller than 2.8 mm would still be within the Rayleigh scattering regime.

10. P6L5: "The abrupt omission of LDR observations above the ceilometer cloud base height appears suspicious as it produces a nearly horizontal feature in Fig. 2d." Can you exclude artefacts of the Doppler spectrum preprocessing, especially noise level estimation in SXPOL and omission of empty spectra in the data?
The CoPol and XPol spectra are processed with the same code. The code to omit spectra to save disk space is the same for both channels. The code estimating the noise level is the same, also. I (CRW) cannot see how processing could be generating artefacts that suppress the detection of warm clouds. The missing LDR observations fits the logic of spherical warm water cloud particle scattering not producing a cross-polarized return signal. To avoid confusion to the reader, this sentence was deleted. See text near P7L8.

11. P6L24: I was not able to find the mentioned spectra profiles in the supplement.
Yes, that was a problem with the lead author did not realizing that there was a size limit (50 MB) and spectra plots were in mp4 animations that are 25 MB per hour file. In order to show the profile-to-profile spectral variability, a random selection of approximately 169 spectra profiles for six different events are now included in the supplement. Also the images and netCDF files being uploaded to the ARM archive are temporarily available on a Google Drive Folder: https://drive.google.com/drive/folders/1whhYC6op1nzMRg93FJYohjkFB6v1uLNU?usp=sharing.

12. P6L25: "This indicates that individual insects appear in the […]" What was the horizontal wind speed in that height?
Good question about horizontal wind. Text was added to the manuscript stating that the surface wind is about 3 m/s and is fast enough to advect passive insects through the radar resolution volume in less than 4 seconds. More analysis is needed to determine whether the insects are actively flying or passively moving with the horizontal wind. See text near P7L29.

13. P7 Fig 2: Please mark the time of the case study (Fig 3 and 6) in that figure.
Yes, a vertical dashed line has been added to Fig. 2 and the caption updated. See Fig. 2.

14. P10L3: "The bottom panel (Fig 3d) […]" Are you referring to Fig 4d?
Yes, correction made. See text near P11L7.

15. P10L16: "from insects (including "atmospheric plankton")" Atmospheric plankton other than insects and its signature in cloud radar observations is not mentioned in Section 3.
Good catch. Atmospheric plankton was added as a possible scattering process in Section 3. See text near P6L26, P6L28, and P6L35.

16. P11L1: "KAZR XPol channel is not sensitive enough to detect non-precipitating liquid cloud droplets" Liquid non-precipitating clouds should not show any LDR, regardless how sensitive the XPol channel is (at least for a single scattering process).
Thanks for pointing this out. The text has been improved with your suggestion. See text near P12L3.

17. P11L5: "[…] that clouds are persistent over 10's of seconds and 10's of meters" But the air velocity, which determines the spectral bin of a signal, might change a smaller timescales. Does this filtering step need to be adjusted to the turbulence conditions?
Yes, you are correct, the air velocity does have a shorter time scale and shifts the cloud into different velocity bins. But the time-height filtering is being done after the spectral processing steps and is using the binary hydrometeor masks. The text was modified to clarify this filtering step. See text near P12L6.

18. P11 Fig 5: Please consider adding color coding to clarify the two branches. Also specify 'small regions' more exactly.
Thank you. Colors and labels were added to Fig. 5 to clarify the two branches. The 'small regions' were explicitly defined. See updated Fig. 5.

19. P11L9: The heading should read "CoPol Texture Algorithm Branch" to be consistent with 4.2.
Thank you. Corrected. See text near P12L12.

20. P11 Eq 5: Is the term in the brackets a matrix or just the maximum out of two alternatives?
It is the maximum out of two alternatives. Equation 5 has been updated and text was added to clarify the calculation. See text near P13L6 and Eg. 5.

21. P12L8: "[…] that for radars with broader beamwidths, the insect peak would broaden […]" Are the broadening processes the same as for distributed targets (e.g. Shupe 2008 JAOTech)?
Yes, the broadening processes should be the same. Because of the narrow velocity range of the point targets, the radar processing also contributes to the spectrum broadening. The text in this sentence was updated. See text near P13L13.

22. P12L20 "Interestingly, enhancements in both max texture and STD texture are visible near 1.8 and 2 km indicating that insect scattering is occurring within cloud scattering regions." Judging from Fig 2, this could be a gap in the cloud with low reflectivities and positive vertical velocity, whereas the higher reflectivity around is associated with negative velocities. Likely, 'close proximity' would be a better description.
Very good observation. Correction was made. See text near P14L2.

23. P15L13: "A threshold of … LDR threshold -15 dB clearly separates the two distributions and is indicated with a dashed line in Fig. 10b." This threshold also fits to the findings of Matrosov 1991 (JAS) and Reinking (1997 JAMC).
Thank you for these references. Text was updated to highlight the work from these two references. See text near P17L10.

24. P18 Section 4.4: Having a spectrally resolved mask, have you considered calculating the moments of the Doppler spectrum for each population? This could provide further insight into the co-occurrence of insects and clouds in the same volume.
Yes, we have calculated Doppler velocity spectrum moments for the different masks. We are still evaluating their quality and expect to release the spectral masks and the moments at a later date.

25. P18L19: The abbreviation QC needs to be defined.
Corrected. Thank you. See text near P20L19.

26. P19 Fig 12: What does v06 stand for? If it's just a version control flag, please consider omitting it.
Yes, it is a version control number. It was removed from the figure. See updated Fig. 12.

27. P21L14 and P22 Fig 14: What is the additional benefit of the Doppler Lidar observations, that could not be derived from the Ceilometer? From the current content, this part of the comparison could be omitted without loosing information.
Okay. Figure 14 was deleted and text describing the Doppler Lidar and TSI in section 2 was deleted. See text near P5L18.

28. P22L13: "[…] cautionary note for future studies is that XPol spectra observations observe fewer insects than CoPol observations". This depends strongly on the signal amplification in the XPol channel and the polarization decoupling of the system.
Well, that is not what these observations suggest (nor the observations of Matrosov 1991 and Rienking et al 1997). The received XPol signal power will always be less than or equal to the received CoPol signal power (other than random noise fluctuations). This is why LDR has negative values (Fig. 10 shows precipitation with LDR less than -20 dB). The cautionary note is to make the reader aware that less power is returned in the XPol channel than the CoPol channel and that if the reader only uses XPol methods to identify insects in the CoPol channel, then the algorithm will miss insects in the CoPol channel. Text was strengthened to clarify this important finding. See text near P24L12.

29. P23L4: "[…] many velocity bins and several range gates". Depends on the technical configuration of the radar, please consider providing physical units (m s-1 and m respectively).
Good point. Typical values are provided to show the stark contrast between point scattering and distributed targets. See text near P25L5.

30. P23L13: "There appears to be relationships between the insect activity index, radar reflectivity and cloud formation." This is a very vague statement. Please be more concrete or or consider omitting it.
Omitted. See text near P25L17.

31. P23L32: Seeing the importance of the issue you are addressing and assuming a broad interest in the community, please consider providing the source code in an open repository similarly to your 2018 paper.
I think we will make the code available in the near future, after it gets converted into Python. Right now, the code is not well documented and written in MATLAB. The Python version will probably be posted so that users do not need a MATLAB license. There is a comment that the code is available from the lead author upon request.