Response to Anonymous Referee #3

The authors developed a cloud and clutter discrimination algorithm for a ground-based millimeter-wave cloud radar system collocated to an MPL. The methodology to separate cloud from clutter is based on multivariate histograms that are used in a Bayes classification approach to provide categorical separation. Spectral width (SW), reflectivity, and linear depolarization ratio (LDR) are used to create joint histograms for cloud and insect clutter. The methodology is tested with a few case studies including shallow cumulus in the warm and cold seasons, uniform stratus embedded within insect layers, and precipitating stratocumulus. Comparisons are made to the MPL cloud base and show generally good agreement in the case studies. The approach is extended to one year of data and a probability of detection of 98% is obtained.

The methods, approach, and use of data all appear sound and the manuscript is organized well. The use of English could be improved in places. The novelty of the methods used in this manuscript should be more clearly called out when compared to previous works. These comments should be considered minor in scope, however.

Response: We thank the reviewer very much for his/her positive comments and suggestions on this manuscript. We have carefully read through the manuscript and corrected some grammar errors, including those pointed out by the reviewer. The novelty compared to previous works has also been described more clearly in the revised manuscript.

Detailed comments:

Overall the manuscript could use a thorough edit for the use of English. One example is the use of 'clutters' rather than 'clutter'

Response: We have carefully edited the use of English in the manuscript, including changing "clutter" into "clutters".

In the Introduction, some clearer description of how this approach follows from, or is different from previous literature, should be added. It appears similar approaches exist in the literature but perhaps in pieces. For instance, insect detection with KAZRs may be better handled in spectra *domain as by [1, 4], and LDR statistics with [2], and a similar but more comprehensive dual pol approach in [3] for scanning radars. Generally, LDR based estimates are widely used in the field as well.*

[1] Luke, E. P., P. Kollias, K. L. Johnson, E. E. Clothiaux, A Technique for the Automatic Detection of Insect Clutter in Cloud Radar Returns. J. Atmos. Oceanic Technol. 25, 1498-1513, doi:10.1175/2007JTECHA953.1 (2008). (this is already cited); [2] Martner, B. E., and Moran, K. P. (2001), Using cloud radar polarization measurements to evaluate stratus cloud and insect echoes, J. Geophys. Res., 106(D5), 4891–4897, doi:10.1029/2000JD900623. (not cited); [3] M. A. Rico-Ramirez and I. D. Cluckie, "Classification of Ground Clutter and Anomalous Propagation Using Dual-Polarization Weather Radar," in IEEE Transactions on Geoscience and Remote Sensing, vol. 46, no. 7, pp. 1892-1904, July 2008, doi: 10.1109/TGRS.2008.916979. (not cited); [4] Williams, C. R., Maahn, M., Hardin, J. C., & de Boer, G. (2018). Clutter mitigation, multiple peaks, and high-order spectral moments in 35 GHz vertically pointing radar velocity spectra. (not cited)

Response: We thank the reviewer for providing these relevant references, and we have cited these in the revised manuscript. We agree that the insect detection with KAZR is well handled in spectra domain as by Luke et al. (2008) and Williams et al. (2018). We think some other methods still have scientific significance, like the TEST algorithm proposed by Kalapureddy et al. (2018), which uses reflectivity measurements to characterize irregular echoes associated with clutter returns. Such methods do not require huge spectral data and the analysis processes are relatively simpler. The LDR statistic methods, such as proposed by Martner and Moran (2001) and Rico-Ramirez and Cluckie (2008), are for sure widely used in the field, but they can only be applied when both co- and cross-polarized reflectivities are available, which may be not the case at low signal-to-noise ratio conditions as mentioned by Luke et al. (2008). That is why we use LDR statistics to create the PDFs and use a spatial filter to deal with these range gates when LDR measurements are unavailable. We have added these descriptions in the revised manuscript.

Lines 90-91 are repetitive

Response: We have deleted the second half of this sentence.

Lines 97-100, it appears the entire basis for the cloud and clutter histograms derives from the use of the MPL cloud base product. Are there other discriminants? How these histograms were obtained should be clearer. Furthermore, how do aerosols (e.g., dust) impact the histograms? Is there any dust in the case studies shown, and would the authors expect dust to hinder the discrimination of clouds and clutter in the algorithm itself?

Response: Yes, the histograms derived from the MPL cloud base product are the basis for the cloud and clutter separation. There is no other discriminant. The histograms are derived through the following steps: (1) we first collect all the reflectivity, LDR, SW data for cloud and clutter at different height and season based on MPL cloud base product; (2) we then divide all the samples into 12 panels according to their time and height ranges for warm and cold seasons separately (as shown in Fig. 5 and 6); (3) in each panel, the probability is calculated by $p(\boldsymbol{X}=\boldsymbol{X}^O|C_i) = n(\boldsymbol{X}=\boldsymbol{X}^O|C_i)/\sum n(\boldsymbol{X}=\boldsymbol{X}^O|C_i)$, where $p(\boldsymbol{X}=\boldsymbol{X}^O|C_i)$ is the conditional probability of discriminants being $\boldsymbol{X}^O$ for class C_i, $n(\boldsymbol{X}=\boldsymbol{X}^O|C_i)$ is the number of samples of discriminants being $\boldsymbol{X}^O$ for class C_i, $\sum n(\boldsymbol{X}=\boldsymbol{X}^O|C_i)$ is the number of discriminant samples being $\boldsymbol{X}^O$ for all classes. We have added the details of calculation in the caption of Fig. 5, as "The size of dots represents the value of probability density, which is calculated as the number of samples in each bin for each class (cloud or clutter) divided by the total number of samples in each bin for all classes."

For the impact of aerosols on the histogram, since MPL is not susceptible to the clutters, we use its cloud base product to separate cloud and clutter samples. All the non-cloud features identified from MPL, which are measured as significant echoes by KAZR, are considered as clutters, including insects, dust aerosols, pollen, or dry leaves. In other words, the clutter type is not the main concern of this study. Here, the MPL cloud base is derived from a feature detection using continuous wavelet transform analyses (Xie et al., 2017) that can well separate cloud and dust aerosols. Based on our current algorithm, we can not identify the clutter type (insect or dust), so we are not sure if there is any dust shown in the case studies. However, we do not expect that the dust would hinder the discrimination of clouds and clutters.

Line 157, not sure if 'discrepant' is the right word

Response: We have changed it to "distinct"

Lines 173-174, while the literature describes the number density and height of insects are temperature-dependent, do the species of insects themselves differ with season? Could a seasonal species dependence of insects have some bearing on the characteristics of the pdfs?

Response: Thanks for this interesting comment. Yes, the insect migration can cause seasonal variation of insect species. Note that cotton bollworm emerging in the far northeast of China would migrate into northern China in autumn, changing the local species of insect (Feng et al., 2007). The species of insects do affect the radar observation, due to their various shape, length, and wing-beat frequency, generating different morphology on spectra domain (Wang et al., 2017). However, such difference normally doesn't affect the reflectivity, LDR or SW (Wainwright et al., 2020), or the created PDF, consequently. Despite that, the difference of radar measurements between various insect species is smaller than that between insects and cloud droplets. Thus, we ignore the seasonal variation of insect species which may have a very small impact on the created PDFs.

Reference:

Feng, H. Q., Wu, K. M., Ni, Y. X., Cheng, D. F., and Guo, Y. Y.: Return migration of Helicoverpa armigera (Lepidoptera: Noctuidae) during autumn in northern China, Bulletin of Entomological Research, 95, 361-370, 10.1079/ber2005367, 2007.

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Wang, R., Hu, C., Fu, X., Long, T., and Zeng, T.: Micro-Doppler measurement of insect wing-beat frequencies with W-band coherent radar, Scientific Reports, 7, 10.1038/s41598-017-01616-4, 2017.

Xie, H., Zhou, T., Fu, Q., Huang, J., Huang, Z., Bi, J., Shi, J., Zhang, B., and Ge, J.: Automated detection of cloud and aerosol features with SACOL micro-pulse lidar in northwest China, Optics Express, 25, 10.1364/oe.25.030732, 2017.