Authors Responses

To the *Interactive comments on* manuscript titled "Simple insect removal algorithm for 35- GHz cloud radar measurements", M C R Kalapureddy et al. *Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-254, 2017*

At the outset, we are grateful to the Editor(s) and all Editorial team for their services/help and untiring timely support and cooperation. We are also equally thankful to all the three Anonymous Referees, for their hearty services in rendering experience and knowledge based comments, those are valuable to us for improving the quality and the focus of the paper.

The point-to-point AR1 responses of the authors are as below:

Anonymous Referee #1 (AR1)

AR1-Comment: The study presented a technique which uses high temporal and spatially resolved reflectivity profiles to extract the cloud echoes from the clutter (mainly from the biota). The proposed technique suggested as a simple and efficient solution for clutter removal, compared to earlier sophisticated techniques based on dual polarization and spectral techniques. I think manuscript has several shortcomings, related to technique and assumptions, poor job of literature review, references and lack of solid conclusions. In its entirety, I would recommend rejection of this paper in its present form.

Response: Thank you! We request AR1 now to review the latest modified version of the paper where we re-written the whole introduction part the manuscript (MS) and cited all possible concern references that come under the scope of the paper and responded also to other valuable referee points. Furthermore, clarity on the technique/algorithm and its main application region has now been clearly come through the revision process in the current modified version of the MS at first Para of section 2 (pg 3) and added basis for TEST (Line 292-295, pg 4-5), including new figures (fig 13 to fig 15) show the potential of TEST in screening out clouds by filtering out biota. Further weakness of TEST under challenging conditions like within cloud and high density biota has been overcome using extra measurements like LDR and SW. This can be seen at the last two paragraphs of Results and Discussion. Thus, the main conclusion of the paper is how simplest way one can remove the biota contribution and preserve true cloud hydrometeor echo and its need for the study of important shallow cumulus/ABL clouds before the actual cloud radar echo weighted measurements consider for any research application purpose. The above revision asked necessary modification to the last section (Summary and Conclusions) from page 11 onwards.

AR1-Major comments: The screening technique authors have implemented using simple measures of reflectivity (or SNR) thresholds and its variability to filter out the clutter has been a usual practice in the cloud radar community as a part of post-processing exercise. The challenge of separating insects from the cloud clutter is difficult due to the lack of clear demarcation between their properties as seen by cloud radar. More often than otherwise, the screening process requires more than one variable, which captures the texture, distribution width, and physical properties of these echoes. With this motivation, some of the earlier studies have devoted their efforts to address this problem using different techniques (fuzzy-logic, spectral technique or polarization properties).

Response: Separating biota from cloud is difficult and challenging but not impossible by the cloud radar if one effectively makes use of advancing radar and signal processing technique (e.g., chirping and DSP) that enables to have the provision of high spatial and temporal resolution radar measurements (1st paragraph of System, Data and Methodology) that can demarcate the cloud echo from insects for example through reflectivity texture (e.g., TEST). With our knowledge, TEST, it is first of its kind effort to consider both reflectivity variance (i.e., dBZ texture) and its rate of change through running average for every 4 seconds. The above point pragmatically working as to identify the time coherence or de-correlation periods associated with clouds and biota echo signature (see newly added figure 15 and its description at pg 11). Moreover, the de-correlation can be evidenced through direct third Doppler power spectral moment; spectral width measurements that clearly show biota exhibits less velocity variance thus the relatively quicker time de-correlation at the pulse scale. In Fig. 2, the zoomed portion of Fig 1, the rounded echo confirms the presence of non-hydrometeor information by their duration of maximum 10 sec which is too small for a cloud to form and then suddenly disappear. So the vertical extension and the time duration of the echoes are the two key factors to discriminate cloud from non-meteorological information. Merits and de-merits of TEST has been brought out exclusively with Figure 13 and 14 that are making use of LDR and Spectral width measurements besides to Z to enhance the proposed TEST algorithm capability under tough conditions like cloud under heavily dense insects clutter.

AR1-Comment: The authors haven't clearly appreciated and addressed the insect removal to the detail that it was needed. They have demonstrated the algorithm with several minutes of data, which doesn't warrant the techniques robustness to apply for other conditions. Authors have made several assumptions about the insect layer depth, their decorrelation timescale without presenting any evidence about the location of the shallow boundary layer clouds, where the insect clutter is very critical. Previous studies (e.g., Geerts and Miao 2005; Chandra et al., 2010) have utilized the long-term observations of insect echoes to study the convective boundary layer, where they have shown that the insect decorrelation times may vary from few seconds to few minutes depends on boundary layer organization. The authors would have shown the distribution of the cloud base locations (from the closest ceilometer data) to justify their presumed insect layers below ~2km. I suggest authors to utilize the supplemental observations (such as ceilometer, microwave radiometer) to present the cloud properties and refine their insect-cloud algorithm based on the locations of cloud layer depth.

Response: **Unfortunately the suggested useful complemented data was not available at and around the radar site. However using some available GPS RS observations from the radar site, the presence of weaker clouds have been proved with auxiliary Figure A2 (please also see the response to the comment 2 of AR#3). Further, we consider the reviewer's well suggested point on the inclusion of shallow boundary layer cloud case with insects clutter (Figure AR1 and AR2) when both have near same reflectivity values (added Figures 13-14). In fact, thanks to the reviewer that now it is clearly illustrating the potential of TEST that lies mostly to the ABL, where shallow cloud evolves, where the affinity of biota are predominant. Below are two examples of such low level/ shallow cumulus clouds with biota clutter where the fine performance of TEST is evident.**

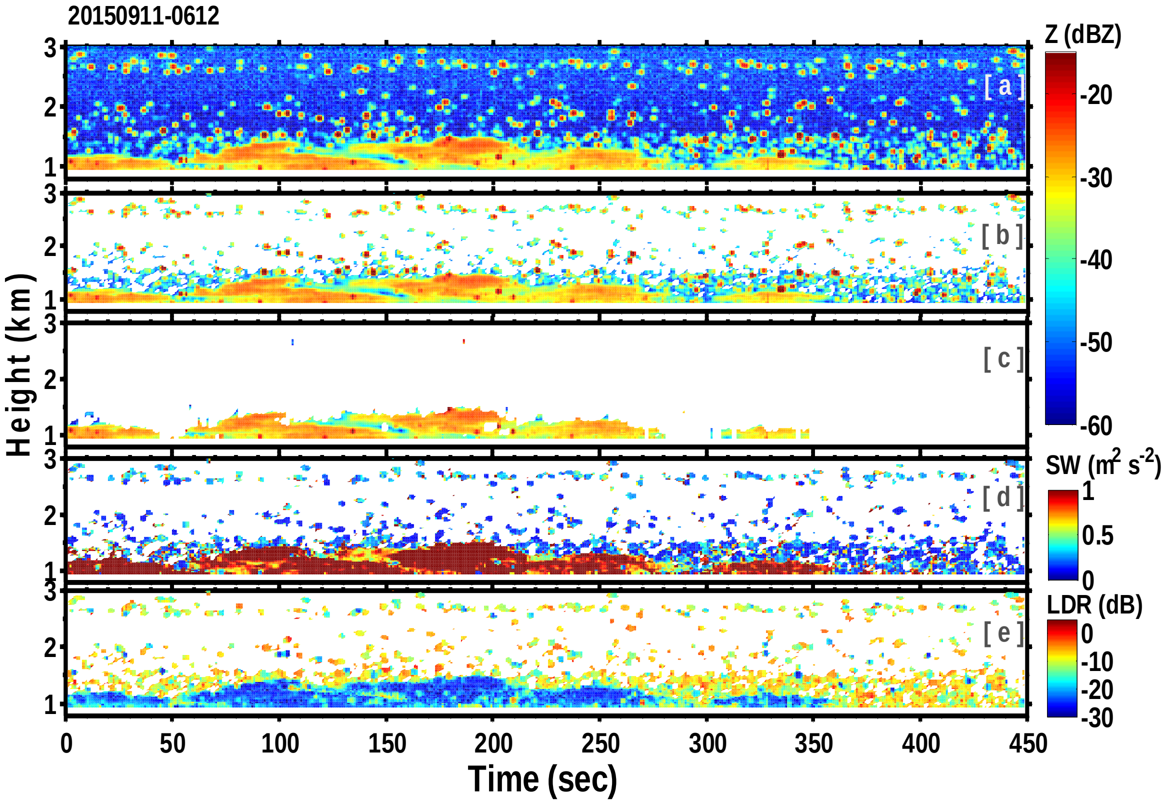

Figure AR1: HTI plot of cloud radar measured (a) Reflectivity (Z), (b) noise removed Z, (c) TEST filtered Z, (d) Spectral Width (SW), and (e) LDR at 0612 UT on 11 Sep 2015.

For demonstration, few typical cases of several minutes have been presented at the beginning but for robustness and application of this algorithm as suggested has been demonstrated with Figure 12 that makes use of several contiguous vertical looking measurements files in a day for more than 6 hours duration. In fact, we are thoroughly using this algorithm for all our cloud radar data (2013-2016) for quality cloud study. Thus, the current work is verified in all kind of atmospheric and environmental conditions around the radar site but only around monsoon seasons of 2013-2016. The typical cases are those (presented in the MS) where the texture differences of reflectivity (with 2-Dim. and HTI plots) and predominant statistical behavior can be clearly seen between insect and cloud. It is evident from that analysis that the biota is confined below 2-2.5 km AGL. For further confirmation of removal of biota, HTI plots for each file in each day have been made automatically within the algorithm for visual re-assurance of the intact cloud vertical structure. Further, presence of biota has also been confirmed using the polarimetric parameters (using earlier published references) from the same radar data, see Figure 11, Figure 13 & 14. We have fixed the maximum low level height as 2.6 km AGL for biota contribution based on reflectivity texture with our manual exposure to all the radar data (i.e., AGL+1.36 km=3.9 km AMSL). In this reference, CBL/ABL depth is not important of

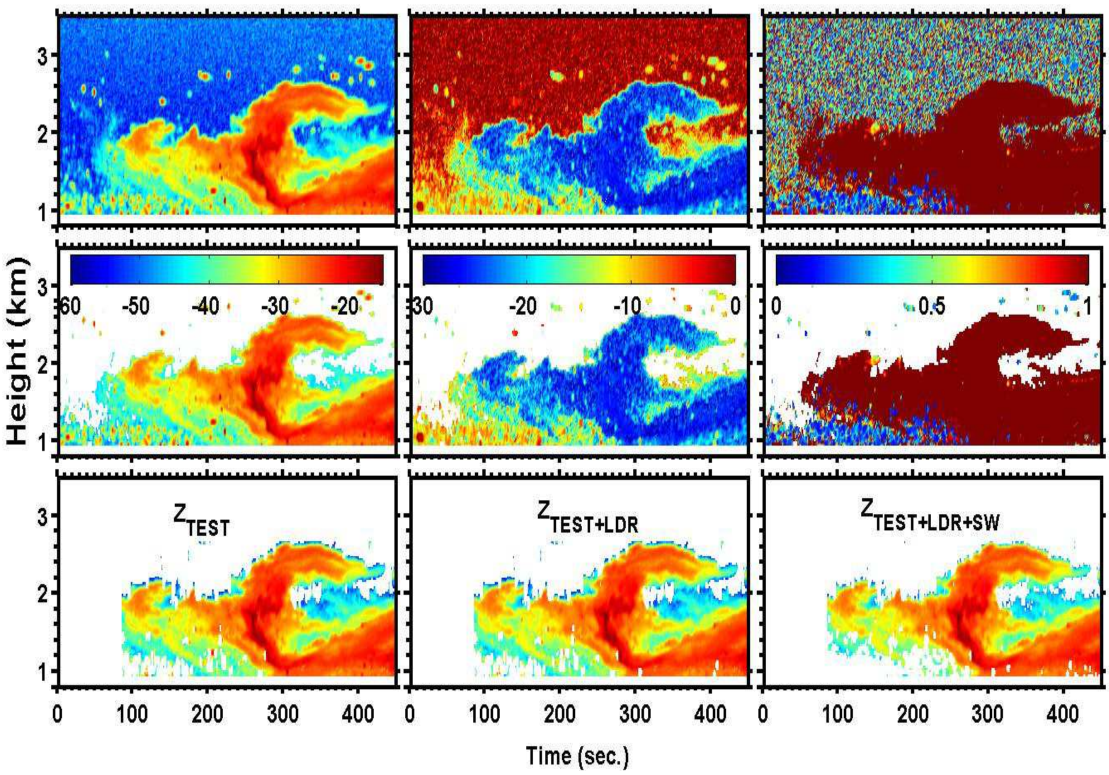

Figure AR2: TEST performance in filtering biota echoes that are co-present with low clouds.

the current idea of the paper and importantly for the hilly, less vegetation radar location.

AR1-Comment:As an alternative solution to the computationally intensive spectral techniques for the insect clean-up (e.g., Luke et al., 2008), a computationally efficient technique to minimize insect clutter have been implemented based on fuzzy-logic algorithm (e.g., Chandra et al., 2013), which takes into account both the physical properties of clouds and different radar moments. This technique can be applied with different levels of complexity based on the supplemental observations (Microwave Radiometer/Ceilometer) you have in addition to radar moments. I suggest authors go through this technique for more details.

Response: Yes, We agree about the computationally intensive spectral technique. Hope you may agree with us that spectral technique is memory and labor intensive too!. Importantly, this paper proposes a 'simple' algorithm that makes use of only off-line radar spectral moments profile viz., LDR, Spectral width and Z. Systematic characterization of Z variability using the local atmospheric vertical structure knowledge besides to the theoretical, statistical, and echo tracing tools are the key components of this study.

AR1-Comment:The basis of the present technique is that the reflectivity distribution could be effective in separating insects from clouds, which may not be the case always. There could be instances when the range of reflectivities from the shallow passive clouds could be similar to the insects (refer to panels, a1 and a2 from the Fig. 13 as in Chandra et al., 2013). This study has taken into account not only the physical properties of cloud (e.g., liquid water path) but also texture signatures in the reflectivity field, the variability of the scatterers inside the radar range resolution from the spectrum width variable-one of the main predictors in insect-cloud separation.

Response: Yes, we have mainly considered the texture signature with Z. For much clairty, TEST algorithm flowchart Figure 6 at pg 6 and its explanation modified slightly at pg 7 (point 4). Agree, Our experience with one second radar data is that most of the insects density might be contributed either one or non insect in the radar beam in a second. The above figure AC1 mentioned case has been explained as Figure 13 in MS. (Figure AR2 is complementing to figure 13).

AR1-Comment:The authors would have shown the technique demonstration effectively with few figures. I feel that there are some figures (Figure 8a and 8b, Figure 11) which don't serve any purpose. Some of the references (cited in the lines 64-98) related to the clutter removing techniques implemented at other frequencies (C- S-Band) were not necessary.

Response: Yes, optimal usage of Figures has been tried. The purpose of Figure 8a and 8b in this paper is vital since it is inferring the Time-series characteristic difference between smooth meteorological cloud returns with its counterpart, noise or biota. Height time variant natures of noise and biota irregularities (more than 1 dB around mean, Z or its SD) are intermittent whereas such time variability is limited to less than 0.5 around mean Z for cloud. Also it is evident from the Figure 8 that insects de-correlation period is always less

than 4-5sec.Thus, height time variant nature of Z and corresponding SD gradient is the key for biota identification. Similarly, Figure 11 demonstrate the important polarimetric capability of the radar as well as to confirm the presence of cloud and biota using polarimetric variables.