Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-254-AC4, 2017

Atmospheric Measurement Techniques
Discussions
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Interactive comment on "A simple insect removal algorithm for 35-GHz cloud radar measurements" *by* Madhu Chandra R. Kalapureddy et al.

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Received and published: 24 November 2017

We are thankful to the Anonymous Referee 3, for the hearty services in rendering his/her experience and knowledge based comments, those are valuable to us for improving the quality and the focus of the paper. The point-to-point AR3 responses of the authors are as below:

Anonymous Referee #3 (AR3)

AR3-Gen. Comment: Millimeter-band radars are very sensitive to detect small targets such as cloud droplets and also insects and other biological particulates (biota) present in great number in the lower atmosphere. Polarization measurement is an efficient mean to discriminate cloud echoes from non meteorological scatterers that

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share in common very low reflectivity. Unfortunately most radars are not equipped with polarization measurements. This short paper proposes for these standard radars a simple technique able to separate meteorological and non-meteorological echoes. It uses only successive vertical reflectivity profiles acquired by a 35-GHz radar operated at vertical incidence with a 50 m pulse length and one second temporal sampling. Because of the high spatial and temporal resolution, most of the time only one or no biota target is present in the pulse resolution volume. In contrast, cloud echo is due to millions droplets that fulfill the pulse volume. As a consequence signal variability at a given range between two vertical profiles is much more important for biota scatterers than for cloud echoes. Signal variability is given here by the standard deviation of the reflectivity over the time of five profiles that corresponds to the typical duration of the biota echoes crossing the antenna beam. The threshold value that separates distinctly biota from cloud is obtained from statistical analysis of a large radar observation set. Indeed this value should be adjusted for a radar having different characteristics. The topic of this study enters the scope of the journal and responds to a real issue for anybody who wants to extract physical quantities from radar signal. The work is put into perspective with past equivalent investigations through a large panel of bibliographic references. The work based on well chosen graphics is convincing and above all the methodology is validated with polarization measurements provided by the same radar. In conclusion this paper that presents a good scientific interest is suitable for publication in Atmospheric Measurement Techniques Journal. However this recommendation is subordinated to the authors consideration of the following comments.

Response: we are grateful to the reviewer's learned summary of the work and thankful for intimate resonance with the central idea of the paper. In fact, above concise summary is so fascinated that it has been adopted with little changes at the last section of the Manuscript!. We do agree on the underlined reviewer statement that with little adjustment to TEST, it will be able to work with other radar (please see below figure AR6 where we drop our 1 sec Z measurements of KaSPR (MS figure 7) to every 4 second and 16 second interval

Main review points

AR3-Comment: 1) Lines 48 to 50 give the list of the source of non-meteorological echoes which comprises insects and other biological particulates (biota). The title refers only to insect and in the text the word insect is nearly always used. Even if the insects is the main source of biological echoes it is a restrictive term. I propose to use in place the word biota introduced by the authors.

Response: Agreed and implemented! Insect word replaced with biota for the whole MS.

AR3-Comment: 2)- In figure A2 strong vertical gradient of humidity is associated with the presence of cloud echoes. We may deduce that also strong refractivity index gradient exists which can be a potential source of Bragg or specular echoes. For information an explanation that this type of echoes, observable with UHF and VHF band radars, has a very low probability to be detected by millimeter-band radars will be welcome.

Response: Yes, indeed it is welcome at cloud radar to see clouds at unsaturated elevated cloud layers that is evident at relatively cooler (T ~ -10°C) height level. This may be something that with increasing altitude even relatively less RH close to above 75-80% is sufficient enough to consider as cloud possibly due to the lower saturation vapor pressure associated with predominant ice than water above the zero degree isotherm levels?! ..Speculating! Furthermore! Possible sensitivity of the 35 GHz cloud radar (~ -36 dBZ; dashed circled region with aside pasted figure AR7 (ref: figure 6 of Kollias et al., BAMS 2007)) to the strongest refractivity index gradient observed to be contributing mainly from huge water vapor gradient (of ΔRH >75% and $\Delta T < 2^{\circ}$C within ~400 m atmospheric slab centered at ~5.2 km altitude; see Figure A2 of the MS) with Alto-Stratus cloud could have been close correct guess to this happens. This further confirms the sensitivity of the cloud radar to detect weaker shallow depth clouds.

AR3-Comment: 3)- The sensitivity of the radar is -60 dBZ at 1 km range (line 95). This value seems to me very optimistic according to the radar characteristics. Give some details on the radar calibration.

Response: Yes, KaSPR operated in zenith FFT mode with below configuration: 50 m range resolution, 25 m range gate spacing, 1:10 pulse compression ratio (0.75* 10 i.e., 75% efficient pulse compression), 5 kHz PRF, 128 FFT length/14 coherent averaging, 20 post averaging will have the minimum detectable reflectivity at 1 km is dBZ= -20log(50) – 10log(0.75*10) – 10log(14) – 10log($\sqrt{}$20) +4.4 = -56.3 Where difference between the calibration constant and noise floor (+55.4 – 51 = +4.4) So, the minimum detectable reflectivity at 1 km is -56.3 dBZ (it could be -53.3 dBZ only if a 3dB threshold above Pn/(FFT length*$\sqrt{}$incoherent integration) that yields a false alarm rate of less than 1%).

AR3-Comment: 4)- May be the high radar sensitivity is due to the use of pulse compression (Table 1). If this mode is used give the effective pulse length, the code moments number and the lower range gate available for the data set presented in the paper.

Response: Yes, used the 3.3 μs pulse length with 10X pulse compression (i.e., compressed to 0.33 μs in the digital signal processor of the system). So, the radar data set used for this work has the effective pulse length of 50 m and lowest range gate available is at 942 m AGL.

In details, KaSPR employs an improved variation of the well known Linear Frequency Modulated (LFM) pulse compression technique. The KaSPR pulse compression technique is amplitude taper (window) (using a Tukey taper with 0.7 taper coefficient; Window function) on the transmitted LFM pulse and the compression is implemented in the digital signal processor system using a least mean squared filter (Mudukutore et al., 1998) to achieve much improved (lower) range side lobes, compared to un-tapered LFM pulse compressed with a matched filter. Ref: Mudukutore, A., Chandrasekar, V., & Keeler, R. J. (1998). Pulse compression for weather radars. IEEE Transactions on Geoscience and Remote Sensing, 36(1), 125-142. DOI: 10.1109/36.655323. These details are added now in section 2 at pg 3 last para.

AR3-Comment: 5)- The term point target is used line 102 for non-meteorological echo. In fact a scatterer is named punctual echo when it is alone in the pulse volume. In that case echo duration is related to the time taken by the target to cross the radar beam, to its radar cross-section and its position relative to the beam axis. All these factors explain the signal variability of biota echoes.

Response: Yes, agree. In fact the word 'point' used for theos biota target echo that can be seen as point/round discontinuous returns (e.g., figure 2 and figure 13 a). Further with NER curves it has shown they follow point and volume radar equation (see modified figure 2 and below figure AR8).

AR3-Comment: 6)- In fig.1, and others equivalent figures, a range (r) correction of the radar signal of the form r2 is used (line 109). It is correct for volume echoes such as cloud echoes, for point targets it is inadequate. The range correction for such backscatters has the form r4.

Response: Yes, agreed. Suitable modification has been made with the text and figure AR8 as pasted below. The suggested range correction for the possible point target is assumed to be confined mostly below 3 km altitude. These curves are also added now and shown as gray dashed curves with their start point are almost maintained. It is interesting to note that the maximum value of mean noise floor (s14; dashed grey lines) is well within s5 (green) curve that was chosen in this work to first qualify the signal above the noise floor either for cloud or insects echo which has been selected for further process to find the time coherence or correlation periods in the next stage to keep only the cloud. Thus this point has already taken care.

AR3-Comment: 7)- When there is an echo at a certain range, the signal at the receiver output is the sum of the receiver noise voltage and the detected backscattered wave. It is therefore necessary to remove the noise power in order to get the backscattered power. It is evident that this has not been done for the presentation showed in the figures such as fig.1.

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Response: Yes, the only spectral moment's profile data has been used in this work (that ensure through signal to noise ratio check for having only backscattered power). This has stated now clealry at the start of section 2. In fact, under weak or no sensible atmospheric targets within the radar sample volume of any radar range gate, the radar spectral moments computation software tracks to pick up the close by background random noise floor peak from the Doppler power spectrum. Actual cloud radar spectra under clear-air condition will have only noise floor at all FFT bins and even at all range gates. It is also quite obvious the case where there was no sensible targets in the cloud radar probing region. Under such void of sensible cloud radar target range gates, the moment's estimation code quite possible to pick up a random noise peak relatively closer to within the Doppler Spectra FFT/velocity bins based on spatial and temporal continuity information. This might have been the reason to have noise Z estimates from the zeroth moment profile. Good thing with this mean background noise is that it is helping to retrieve weaker cloud boundaries some extent using theoretical NER curves.

AR3-Comment: 8)- Line 111: Receiver noise is made of thermal noise generated within the receiver chain and also of other sources which are taken into account through the noise figure of Table 1.

Response: Yes, correction implemented at line no 275-276.

AR3-Comment: 9)- Give more details on the computation of the running mean and standard deviation (line 136) of the successive vertical profiles of reflectivity. In particular it is important to precise if these quantities are computed before or after noise removal.

Response: Mean and standard deviation of the successive vertical profiles of reflectivity (after noise removal) are computed. In fact, we used offline spectral moments data for this entire work. It is first attempted to find out the noise floor using sensitivity (NER) curves and found that S5 curve is near 3-db higher than the maximum observed noise floor of the KaSPR. Once noise is removed only those echoes are allowed which are higher than S5 curve to segregate cloud and biota. Biota point returns are mostly confined below 3 km altitude with significant shift of mean noise floor just below 1.5 km towards higher (S14 curve; based on the point target NER i.e., r4 X Zstart range) but this still lies well within S5 curve (see above figure at the response of AR3 comment 6) to allow for further process to refine them using standard deviation or time coherence to determine cloud or not. Then de-correlation time of cloud and biota have been found out using running mean and standard deviation of different time interval. Cloud being an meteorological echo changes gradually and so having de correlation period more 40-110 sec. But for insects being spurious in nature it de-correlated quickly, within 4-10 sec. From this computation 4sec has been taken as a key segregator between biota and cloud.

AR3-Comment: 10)- Line 161: Receiver noise is not en echo but a signal generated in the receiver chain.

Response: Admitted the mistake, correction implemented at 1st paragraph of Results and Discussion, line no 342, 361, 362, and 364.

AR3-Comment: 11)- A statistical de-correlation time is introduced line 174. I do not understand very well how it is computed. I think it is related to the standard deviation of the reflectivity. Give the formula that links de-correlation time and reflectivity standard deviation. In figures 3 and in the text the unity used for the standard deviation is not given.

Response: Yes, it is related to the 4-point running mean and standard deviation. (here SD is for Z thus its unit dBZ apply). It is hypothesizing here (provided now in MS at page 290-295) that the running mean and standard deviation of ∼4 seconds reflectivity profiles (i.e., sliding interval of 4 seconds) works in identifying all non-hydrometeor returns. Furthermore, the time coherence of radar returns at every range sample can be checked for every 4 seconds as window period to infer the echo power de-correlation time or degree of coherence period associated with biota return. In order to prove this, the below figure AR9, is worked out to find the correlation where left panel represents the typical HTI plot of Z measurements for low level/ shallow cumulus cloud in the presence of biota and right panel shows the simple auto correlation function (ACF) having lag (0-300 sec) correlation corresponding to the reflectivity time series of shallow cumulus cloud (base, mid, top) and biota heights at 1.5 and 2.6 km. From the ACF analysis it is clear that biota shows quicker (∼4 seconds) de-correlations periods than cloud (∼ 40-170 seconds). It is also to be noted that clouds may show varied de-correlation periods above 30 seconds but insects mostly de-correlate very much less than 10 seconds. Hence, the hypothsis for TEST proves here with. These discussions and newly added figures (13-15) are can be seen with MS at page 4, 10-11 and 37-39 .

AR3-Comment: 12)- lines 218 to 219 ...biota that are found to extend less than 2-4 height bins each of 25 m... : vertical spreading of a point echo is expected to extend over half pulse. How do you explain this large spreading that can approach 2 pulse lengths. Is the use of a compressed pulse that produces this increase.

Response: Yes partially. In fact, the used pulse width is 3.33 μs with 10X LFM chirp compression with sampling in range (range gate spacing) at every 25 m. So, the uncompressed range bin width of ∼500 m that become 50 m after 10X pulse compression. It is quite possible that biota movement can confine sometime in-between two range gates then the biota echo spreading can confine maximum of 100 m. This could be the reason. However, small correction has now made in the MS that biota echo extends maximum of 2 range gate intervals of each 50 m or 4 range gate spacing of each 25 m. See these detials with MS at line no. 368-370, pg 6, and line no. 438-439 page 7 and modified first Para of MS Section 2.

AR3-Comment: 13)- I suppose that the radar has Doppler capability because line 263 and 264 PulsePair and Fourier Transform are cited. Doppler spectra width contains information at the pulse scale on the de-correlation time of the echoes. It could have been used instead of the reflectivity standard deviation. Did you try to analyze this quantity to discriminate echo type.

Response: Yes, KaSPR having Doppler capability and the 2nd moment velocity variance/Spectral width measurements are available. Thanks to referee that TEST results has now been able to cross checked and found that less spectral width values (∼0.3 m2s-2) confirmed the shorter coherence time / short temporal correlation associated with biota. Thus TEST, used running mean and S.D from set of 4 profiles, is working to ensure the biota and cloud through their de-correlation time less than 5 sec. interval. Therefore, TEST is simple but potential because that makes use of single Z parameter but critically through to track its change both at spatial and temporal levels. However, TEST output Z needs to further constrained with SW and LDR thresholds that are found be advantageous to have best possible cloud only radar returns mainly within cloud region. New Figure 13 and the relevant discussions have been added in this regard to the MS at page 10-11.

Note: Referee figure quoted as 'Figure ARX' and MS figure as 'Figure X' Please also see pdf responses attached

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2017-254/amt-2017-254-AC4-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-254, 2017.

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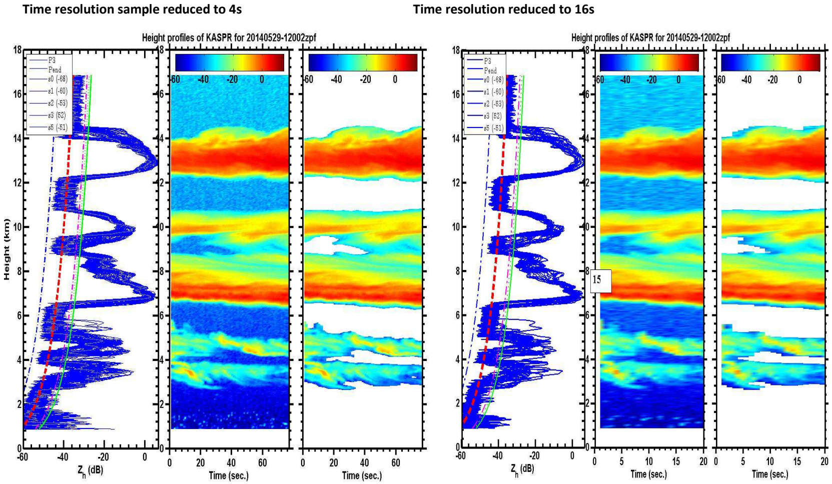

Time resolution sample reduced to 4s

Time resolution reduced to 16s

Height profiles of KASPR for 20140529-12002zpf

Height profiles of KASPR for 20140529-12002zpf

Fig. 1. Figure AR6: KaSPR 1s (see figure 7 in MS) resolution Z profiles are re-sampled at 4s (left three panels) and 16 S. Biota echo seen differently at different time interval sampling.

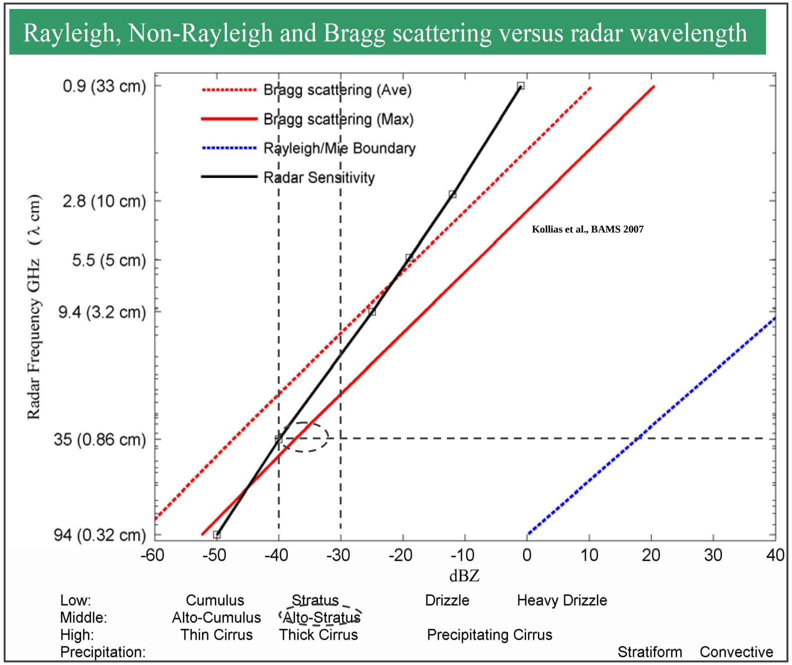

Fig. 2. Figure AR7: Atmospheric radar echo scattering Vs radar wavelengths (taken from Kollias et al., BAMS 2007).

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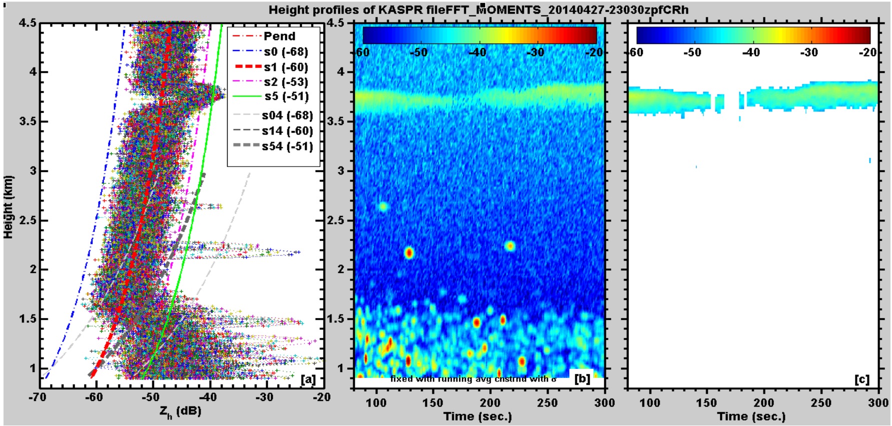

Fig. 3. Figure AR8: Radar Sensitivity curves are now using range correction to the radar backscattering based on the volume (rˆ2 form) and point radar equation (rˆ4 form).

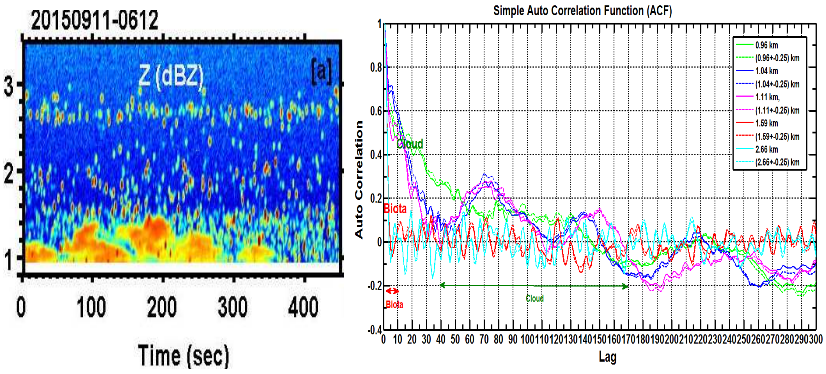

Fig. 4. Figure AR9: Shallow cumulus cloud present with biota (HTI plot) and (right panel) is AFC based 0-300 lag correlation for cloud and biota.