Algorithms for Filtering Insect Echoes from Cloud Radar Measurements

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Introduction

The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts (UMASS) deployed an automated 95 GHz atmospheric radar at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site for 9 months in 2001 during the Atmospheric Radiation Measurement (ARM) multi-frequency radar intensive operations period (MFR-IOP). The purpose was to evaluate the utility of 95 GHz radar for discriminating between liquid clouds and non-hydrometeor echoes and to compare seasonal measurements of 35 GHz and 95 GHz non-hydrometeor clutter. We presume that these non-hydrometeor echoes are mostly insects. Previous analysis of measurements collected with the SGP-CART 35 GHz millimeter wave cloud radar (MMCR) show that it is often not possible to discriminate insect and cloud echoes. At 35 GHz, insect and liquid cloud echoes have similar morphologies and Doppler signatures. However, prior comparisons of simultaneous 35 GHz and 95 GHz reflectivity data show that 95 GHz radar is less sensitive to insects than 35 GHz radar (Khandwalla et al. 2001).

In this paper we present several algorithms derived empirically from MFR-IOP data that identify and remove insect echoes, which are viewed as unwanted contaminants by the could radiation community. Algorithms fall into 2 categories: (1) those using 95 GHz measurements only and (2) those combining 35 GHz and 95 GHz measurements. The first category of filters is based on the linear depolarization ratio (LDR) that identifies insects when LDR is large. The second is based on the dual-wavelength ratio (DWR) with DWR >10 dB implying insects. Additional filters using dual wavelength ratio (DWR) filters, reflectivity and radiosonde temperature data accurately filter insects under a variety of meteorological conditions. We also characterize measurements for clear days and days with high airborne insect densities to justify the use of these variables for discriminating between clouds and insects and other targets.

Simple Case Study of Stratified Cloud and Insect Layer

Figure1a shows a 35 GHz image observed on September 12, 2001, of a stratified cloud layer with insects present below the cloud. The accompanying histogram in figure1b shows slight insect contamination as evidenced by the difference in measurements between 95 GHz and 35 GHz radars with 95 GHz measurements having lower numerical values due to less sensitivity to insects. Figure 1c shows a 95 GHz image for the same day. The histogram in figure 1d illustrates nearly identical 35 GHz and 95 GHz values after filtration algorithms have been applied, demonstrating that 95 GHz is equally sensitive to clouds but less sensitive to insects. Insect scattering regimes dominate in the Mie area while cloud scattering regimes dominate in the Rayleigh region. Because scattering efficiency is reduced in the Mie region, 95 GHz radar observations thus are less sensitive to insects than 35 GHz radar observations.

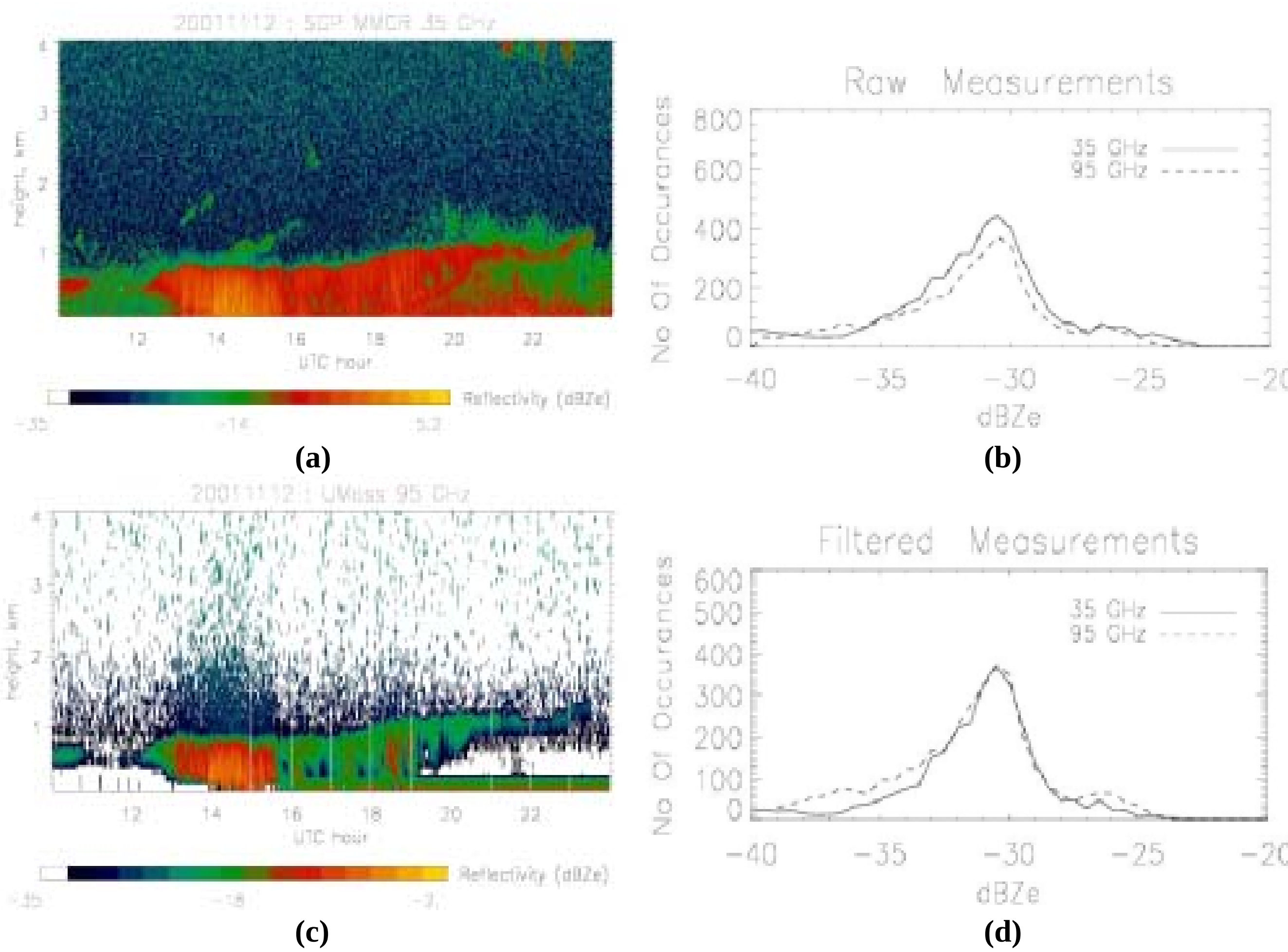

Figure 1. Case study with few insects showing agreement at 35 GHz and 95 GHz.

Mixtures of Clouds and Insects

Figure 2a shows a 35 GHz reflectivity image of clouds embedded in insect layers making it difficult to identify the cloud signal. The 95 GHz image in figure 2c reveals a cloud signal with insects visible below the clouds. The reflectivity histogram in figure 2b shows significant contamination of insect echoes in 35GHz compared to 95GHz and in figure 2d demonstrates that even after filtration, 35 GHz pixels are still contaminated by insect echoes although it is possible that drizzle might be contributing to the contamination. The histogram in figure 2d indicates that the high insect density influences cloud reflectivity values at 35GHz. Compare these results with the histogram in Figure 1d on September 12, 2001, in which 35 GHz and 95 GHz values are almost identical after filtration. In the next section, we describe the filters used to achieve these results. Other instruments present at the SGP-Cart site such as MPL, do not appear to be useful in distinguishing clouds from insects. MPL observations can often detect cloud bases but this signal appears to be unreliable when deep convection has recently occurred.

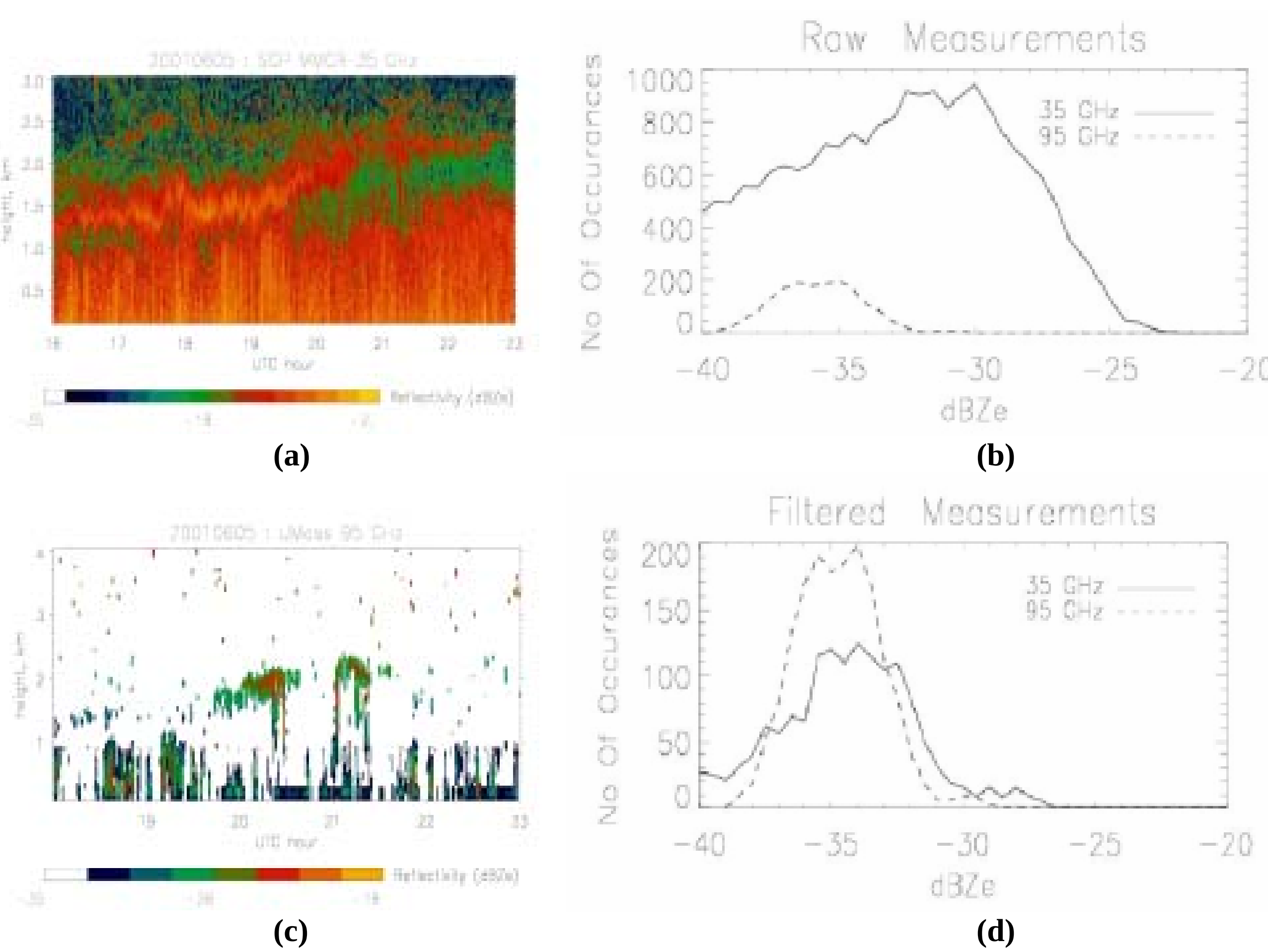

Figure 2. Case study with insects showing contamination of 35 GHz reflectivity.

Filters

We developed filters based on two types of measurements, namely the linear depolarization ratio (LDR) and the dual wavelength ratio (DWR). We found that other measurement variables such as velocity, differential reflectivity, and integrated liquid water content (LWC) are not useful in discriminating clouds and insects. For example, insect and cloud velocity are similar and indistinguishable. Differential reflectivity is noisy and may average to 0 dB in the case of randomly oriented insects, which appears to be typical of non-migrating insects. LWC can show the presence of cloud or lack of cloud, but it cannot distinguish features in mixtures of clouds and insects.

Single Radar Frequency LDR Filters

LDR is calculated from the following formula.

$$LDR = 10\log(P_{\perp}/P_{\parallel})$$

$P_{\perp}$ = Cross Pol. Echo

$P_{\parallel}$ = Co-Pol. Echo

We developed two LDR based filters with the following specifications where -30 dB corresponds to the polarization isolation of the antenna.

1. LDR > -30 dB = > Insects
2. LDR > -30 dB + Median Filter

Pixels containing LDR > -30dB are removed from the reflectivity image. Figure 3a, shows a 35 GHz radar measurements of obtained on September 20, 1997. Figure 3b illustrates LDR for the same time period. The top layer with speckle in figure 3b is cloud embedded with insects. This method has its limitations. We are unable to conclusively determine whether the bottom layers contain insects and clouds or insects only because high insect density overwhelms any cloud pixels that may be present. The LDR filter in this case removes some cloud echoes as well as evidenced by figure 3c. The insect echoes removed are interpolated using surrounding pixels creating holes in the cloud region. The speckle due to low signal to noise ratio can be removed using a median filter. Note that in order to discriminate the melting layer from insect returns, we must consider temperature to ensure the accuracy of the LDR filter.

Since LDR cannot be measured when the signal to noise ratio is weak, insect contaminated pixels can be erroneously reported as cloud. So not all insect echoes are eliminated. The median filter that removes residual insect echoes also sometimes removes cloud pixels. LDR filters do not work in the case of cloud and insect mixtures with high insect density. While LDR filters can be developed using data from only 35 GHz radars, LDR based filters do not perform well in all cases. Thus, 35 GHz radars alone are insufficient to solve the insect clutter problem

Two Frequency Methods Using the DWR

Filters based on DWR require measurements from both 95 GHz and 35 GHz radars. The formula for DWR is the following:

$$DWR = 10\log(Z_{35}/Z_{95})$$

The DWR simple model of insect scattering for equivalent spheres shows that reflectivity measurements for insects greater than 1mm will be significantly larger (by 2 orders of magnitude) at 35 GHz than at 95 GHz (Khandwalla et al. 2001). However, cloud signals remain equivalent at both wavelengths thus implying that only the insect signal is suppressed at 95 GHz by 2 orders of magnitude.

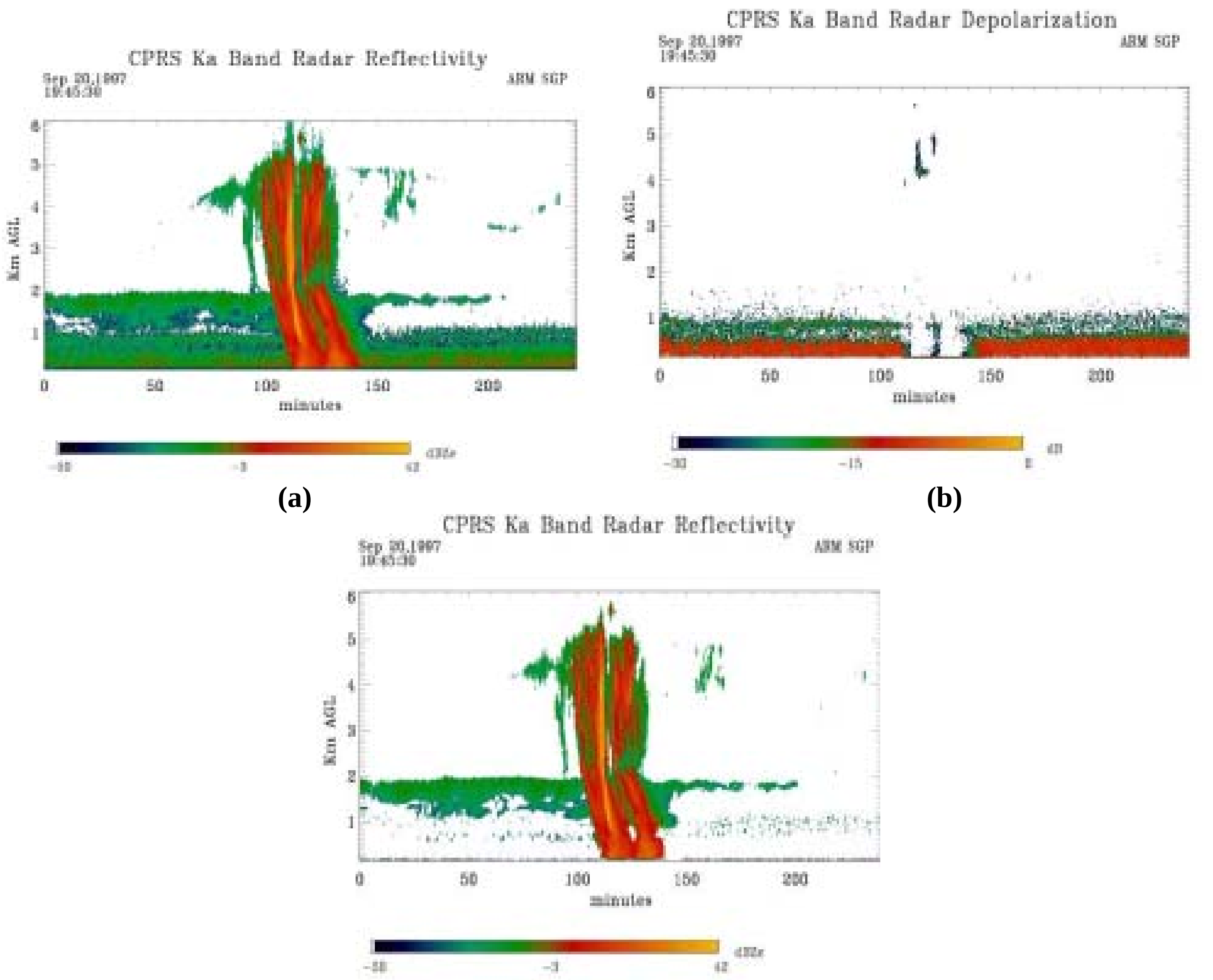

Figure 3. Example of LDR filter (Sekelsky et al. 1998). (a) 95 GHz image (b) LDR measured by 95GHz radar, and (c) filter 1 results showing the elimination of insect and some cloud echo.

Using this property, we developed several DWR based filters empirically that can be used on 35 GHz and 95 GHz data in Oklahoma:

1. DWR > 10 dB => Insects
2. DWR> -10 dB + Z_{95} >-10 dBZe + T > 0 C => Insects
3. DWR >-10 dB + + Z_{95} +T > 0 C + Median Filter => Insects

While filter 3 is sufficient to remove some insect echoes, it also removes precipitation and ice cloud echoes. Filters 4 and 5 are designed to work under a variety of metrological conditions as they do not appear to affect other hydrometeor signals.

Figure 4a shows a 95 GHz time-height image measured on June 5, 2001. Figure 4b, illustrates the results of filter 3. Filter 3 also eliminates some cloud echo. Filter 4 results shown in figure 4c are the most promising. Filter 5 in figure 4d while eliminating speckle, also removes some cloud echo.

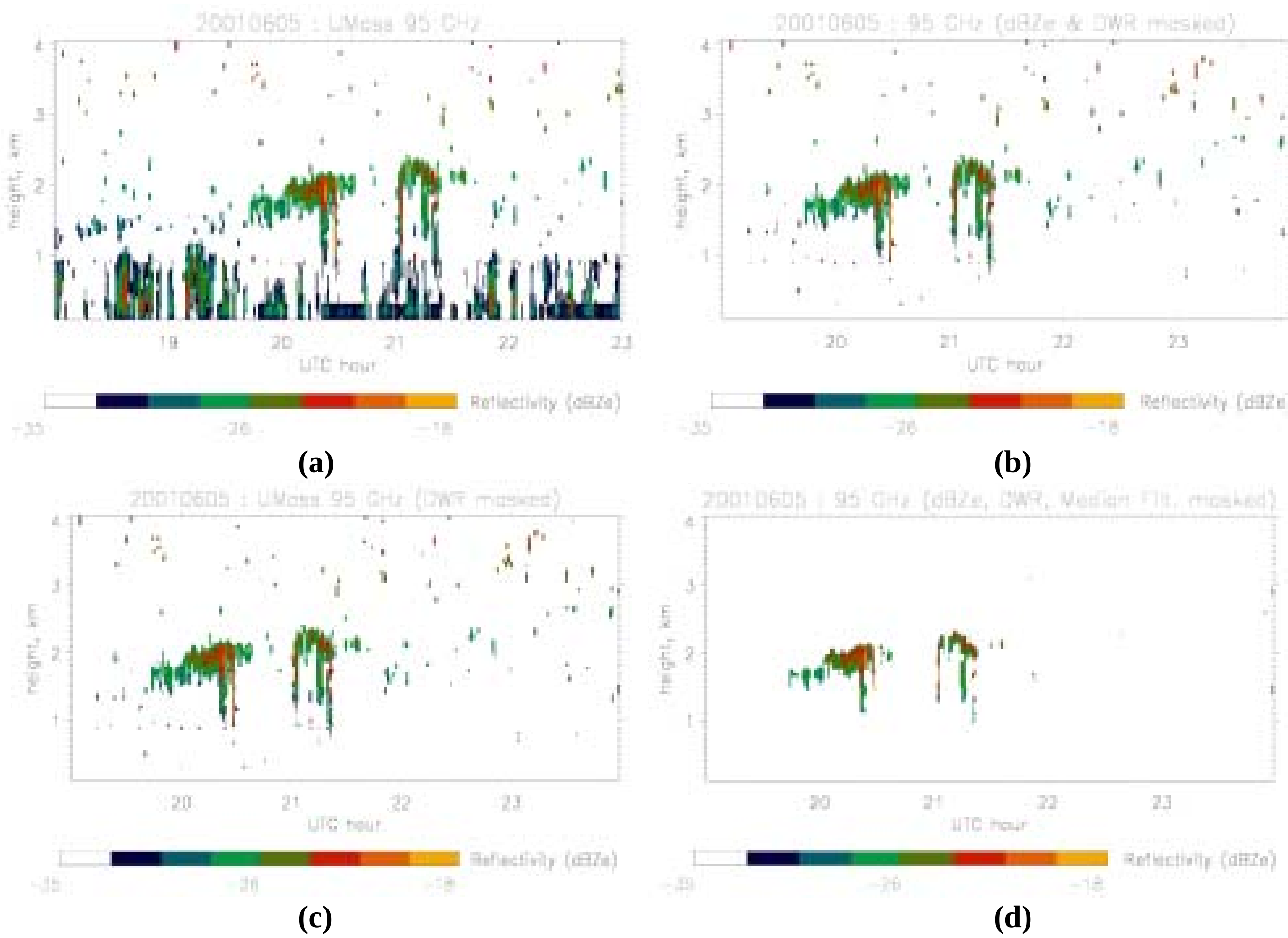

Figure 4. Raw and filtered data at 95 GHz (a) 95 GHz measurements, (b) results from filter 3, (c) results from filter 4 with speckle, and (d) results from filter 5 with some cloud echoes being eliminated.

Conclusion

DWR filters are more effective than LDR filters. LDR based filters do not remove all insect echoes as LDR is not measurable when signal-to-noise ratios are low and LDR can only identify contaminated pixels when clouds and insect mixtures are not present. DWR based filters successfully eliminate insect clutter from time-height images to reveal cloud echoes even in insect and cloud mixtures. Thus both, 95 GHz and 35 GHz radars must be used to collect measurements for developing DWR based filters. 35 GHz and 95 GHz polarimetric radars by themselves may be insufficient for eliminating all insect echoes while retaining cloud. However, at 95 GHz, most insect echoes are weaker than cloud echoes. This means that the possibility of cloud contamination by insects is greatly reduced at 95GHz.

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