MMCR Polarization Measurements for Evaluating Stratus Cloud and Insect Echoes

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Introduction

Recently, millimeter-wave cloud radars (MMCR) have been added to the extensive arrays of ground-based remote sensors at the Cloud and Radiation Testbed (CART) sites. These 35-GHz radars have very high sensitivity that enables them to detect most visible clouds overhead (Moran et al. 1998). Unfortunately, the high sensitivity also allows the MMCR to detect insects, bits of vegetation, ash, and other small particulates that are commonly suspended in the convective boundary layer at continental locations in the warm seasons. In the remainder of this article, these various non-hydrometeor targets are referred to simply as “insects.”

For the Atmospheric Radiation Measurement (ARM) Program, where the objective is to identify cloudy regions and their physical properties, the insect echoes pose a serious problem because the desired MMCR reflectivity signal from low-altitude clouds is often contaminated to an unknown degree by the unwanted contributions from these non-hydrometeor targets. The problem is especially prominent at the Southern Great Plains (SGP) CART site in Oklahoma in spring, summer, and fall, where statistics from 1997 (Clothiaux et al. 2000) indicate the MMCR data from boundary layer heights probably contained insect contaminants 70% to 80% of the time. This article, which is a condensed version of Martner and Moran (2000), describes a dual-polarization radar method to remedy the insect contamination problem. Only clouds of liquid water droplets, such as stratus, are addressed. The method does not apply if low-altitude ice crystals are present, but insect contamination is seldom a problem in cold situations when ice exists.

Adding Dual-Polarization Radar Capability

As a demonstration project, the National Oceanic and Atmospheric Administration/Environmental Technology Laboratory (NOAA/ETL) is adding dual-polarization measurement capability to the spare MMCR in Colorado. This will allow the type of target to be inferred, based on shape information contained in the depolarization measurement. The depolarization ratio (DR) is a parameter that depends on the aspect ratio or approximate shape of the targets and their orientations, but it is independent of their sizes and concentrations. The less spherical the target, the greater the amount of depolarization it produces in the backscattered signal. Thus, spherical stratus cloud droplets produce essentially no depolarization; whereas, most insects are comparatively very non-spherical and cause a much greater degree of depolarization. Therefore, dual-polar cloud radar data can identify when insects are present and absent, and uncontaminated cloud periods can be easily identified in this manner (e.g., Sekelsky et al. 1998).

However, for periods when insects are present, the dual-polar radar alone cannot determine whether or not cloud droplets are also present. This uncertainty can be resolved by incorporating simultaneous data from the micropulse lidar or laser ceilometer instruments, which detect stratus clouds easily, but almost never detect insects. Figure 1 illustrates how this combination of instrumentation can unambiguously discriminate between all four possible situations: no cloud or insects, cloud only, insects only, and

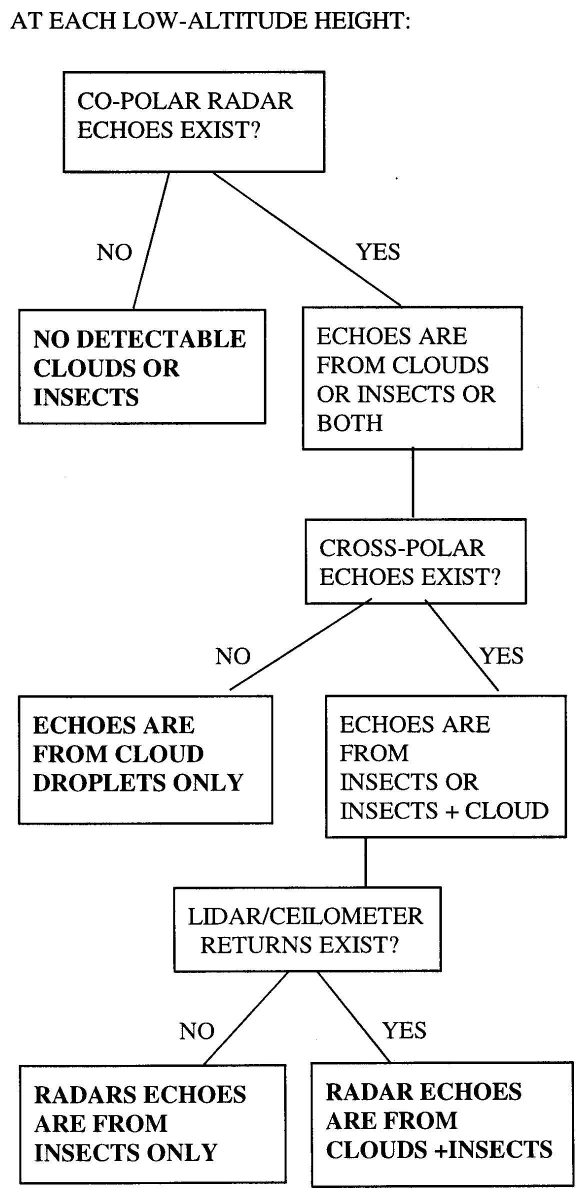

Figure 1. Polarized MMCR and lidar cloud/insect detection.

cloud + insect mixture. This radar echo stratification will be beneficial to ARM cloud research. However, it is also desirable to determine the fraction of the observed radar reflectivity, which is caused by the cloud droplets when a cloud + insect mixture exists.

Mixtures of Cloud Droplets and Insects

The theoretical development for assessing the reflectivity and depolarization ratios of constituents in a mixture is presented in detail by Martner and Moran (2000) who show

$$\mathrm{dBZ_{ch}} \approx \mathrm{dBZ_{cm}} + 10\log\left[1 - 10^{0.1(\mathrm{DR_m} - \mathrm{DR_i})}\right], \quad (1)$$

where the convenient logarithmic expression for radar reflectivity factor, Z in mm^6 m^{-3} has been used (dBZ = 10 log Z). This equation expresses the desired cloud droplet contribution to the reflectivity at each point (dBZ_{ch}) in terms of the observed total co-polar reflectivity of the mixture (dBZ_{cm}), the observed depolarization ratio of the mixture (DR_m), and an estimated, or recently measured, depolarization ratio that is representative for the insects alone (DR_i).

Using Linear or Circular Polarization

A primary factor affecting the accuracy of dBZ_{ch} computed from Eq. (1) is the degree to which the estimate of DR_i adequately represents insect depolarization ratios. Equation (1) is presented in graphical form in Figure 2, where it can be seen that if DR_m and DR_i differ from each other than more than about 3 dB (left-hand 80% of the curve), the cloud droplets dominate the mixture's observed reflectivity, and large errors in DR_i result in small inaccuracies for dBZ_{ch}. The estimate of DR_i can be improved if the radar transmits circular polarization rather than linear polarization, as in the current MMCR design, because the effects of orientations of the scatterers is minimized for circular depolarization ratio measurements. Figure 3 shows distributions of linear depolarization ratio (LDR) values observed with the spare MMCR in Colorado and circular depolarization ratio (CDR) values from the NOAA/K radar in Manitoba, respectively, for a limited sampling of boundary layer insect targets during cloudless periods. As expected, the CDR distributions are narrower, having standard deviations that are less than half those of the LDR data. Thus, we recommend that the MMCR hardware be modified to transmit circular polarization, because it will result in better estimates of DR_i for use in Eq. (1), and, hence, in more accurate estimates of dBZ_{ch}.

Even moderately large errors in dBZ_{ch}, however, are likely to produce acceptably accurate remote sensing retrievals of stratus cloud microphysical parameters, because retrieved parameters are not strong functions of the observed reflectivity. For example, in the radar and microwave radiometer retrieval method of Frisch et al. (1995) that has been adapted by the ARM Program, the retrieved median cloud droplet size is related to the 1/6th power of the reflectivity, and the liquid water content is not dependent on calibrated reflectivities at all. In a more recently proposed retrieval method that utilizes radar data alone, an error of ±5 dBZ results in a retrieved droplet effective radius error of only about ±1 micron (Frisch et al. 2000).

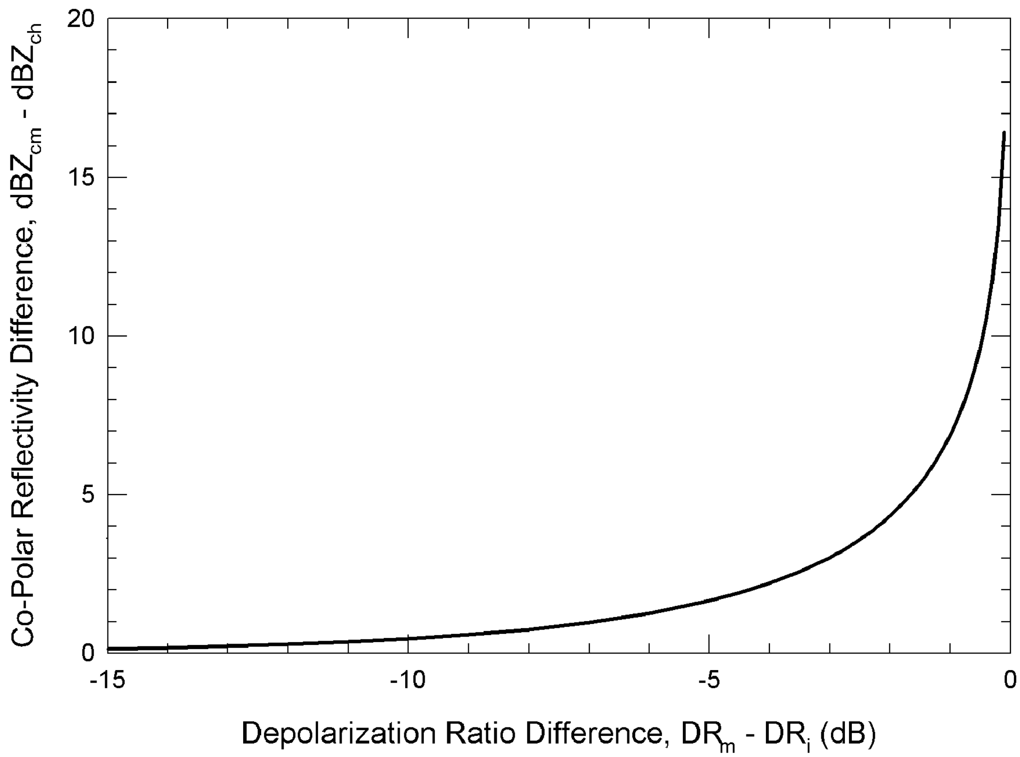

Figure 2. Reflectivity and depolarization ratio relationship from Eq. (1) for a mixture of cloud droplets and insects.

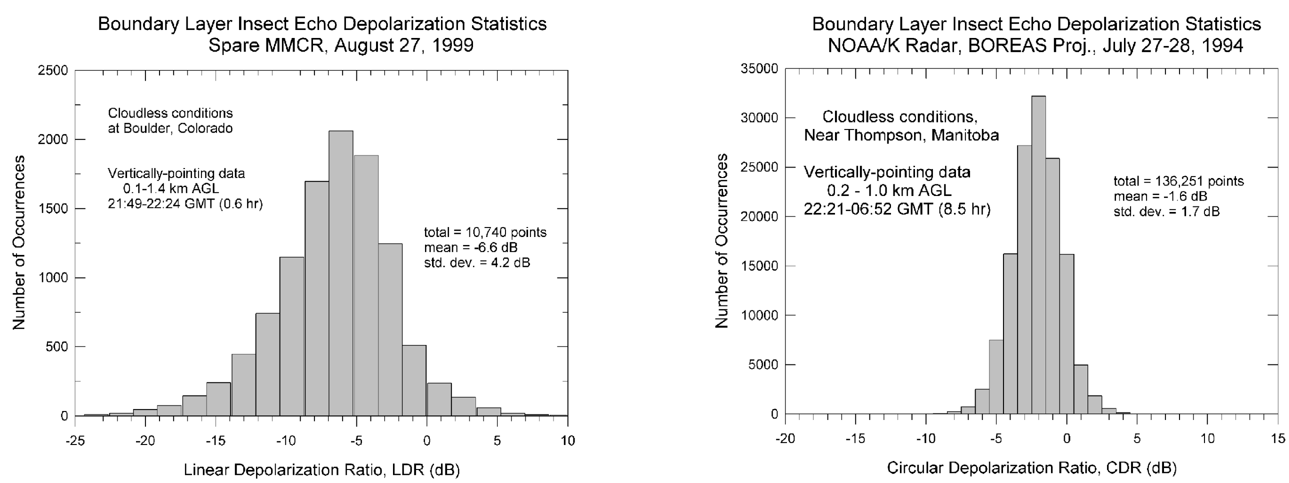

Figure 3. Histograms of insect echoes. LDR values from dual-polar MMCR tests in Colorado (left) and CDR values from NOAA/K radar in Manitoba, Canada (right).

Summary and Conclusions

Suspended insects and other non-hydrometeor particulates are commonly detected in and near the planetary boundary layer by the MMCR at the SGP CART site. Radar reflectivity patterns of these targets are difficult to discern from those of stratus clouds, and therefore these particles represent undesirable contaminants for automated cloud-detection algorithms. Radar polarization measurements offer a means of distinguishing between cloud droplets and these contaminants, based on shape information contained in depolarization ratio observations. Dual-polarization capability is being added to the spare MMCR in Colorado as a demonstration project. A procedure is presented that allows dual-polar MMCR data and simultaneous micropulse lidar or laser ceilometer data to unambiguously determine the presence of cloud droplets alone, insects alone, or mixtures of the two at the CART sites. Theory is also developed for estimating the contribution of cloud droplets to the observed reflectivity of an insect and droplet mixture using the dual-polarization data. Preliminary results indicate that the method provides more accurate estimates if the radar transmits circular polarization rather than linear polarization because the effects of target orientation are minimized.

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