The Lidar Dark Band: An Oddity of the Radar Bright Band Analogy

K. Sassen
Department of Meteorology, University of Utah
Salt Lake City, Utah

R. E. McIntosh and S. M. Sekelsky
Microwave Remote Sensing Laboratory
University of Massachusetts
Amherst, Massachusetts

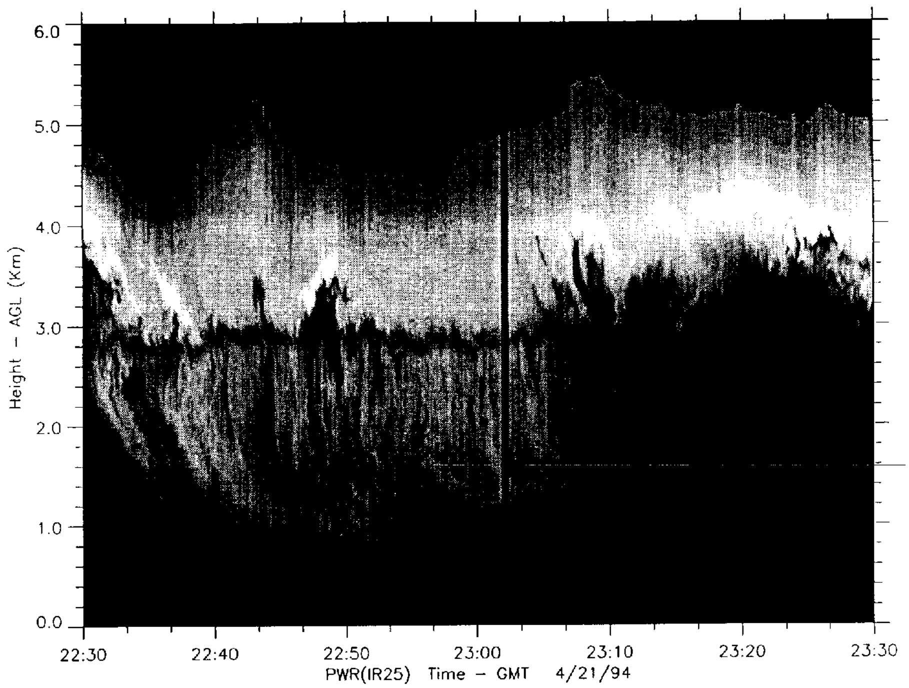
It has long been recognized that rain at the surface often begins as snow in the elevated subfreezing portions of the atmosphere. Attempts to comprehend the details of this process have, over the years, illuminated fundamental properties of mixed phase clouds and the production of precipitation. Similarly, the unique challenges presented by the evolution in the scattering of electromagnetic waves by hydrometeors undergoing the solid-to-liquid phase transition have contributed to advancing our basic understanding of radar and lidar observations of the atmosphere. Since the time of pioneering World War II radar research, anomalous returns from the melting layer have been known as the bright band because of the bright appearance of the layer of melting snow on radar display oscilloscopes (Battan 1973). In addition to the enhanced radar reflectivity factors, increased depolarization and a rapid change in Doppler-derived particle fallspeeds also characterize the melting layer. These attributes result from a combination of factors, including the effects of wet snowflake nonsphericity, the difference in dielectric constants between water and ice, and the large increase in fallspeeds of raindrops.

Surprisingly, since it happens for dissimilar reasons, a lidar bright band phenomenon also occurs at optical frequencies (Sassen 1977a). In this case, it is essentially the increase in particle size encountered while ascending through the melting region that initially causes increased backscattering, followed soon afterward by overwhelming attenuation, that defines the returned energy peak known as the lidar bright band analog. This peak, however, occurs in the snowfall typically above the 0°C isotherm. On the other hand, lidar depolarization appears to maximize near the bottom of the melting layer from wet snowflakes just before they collapse into raindrops (Sassen 1975).

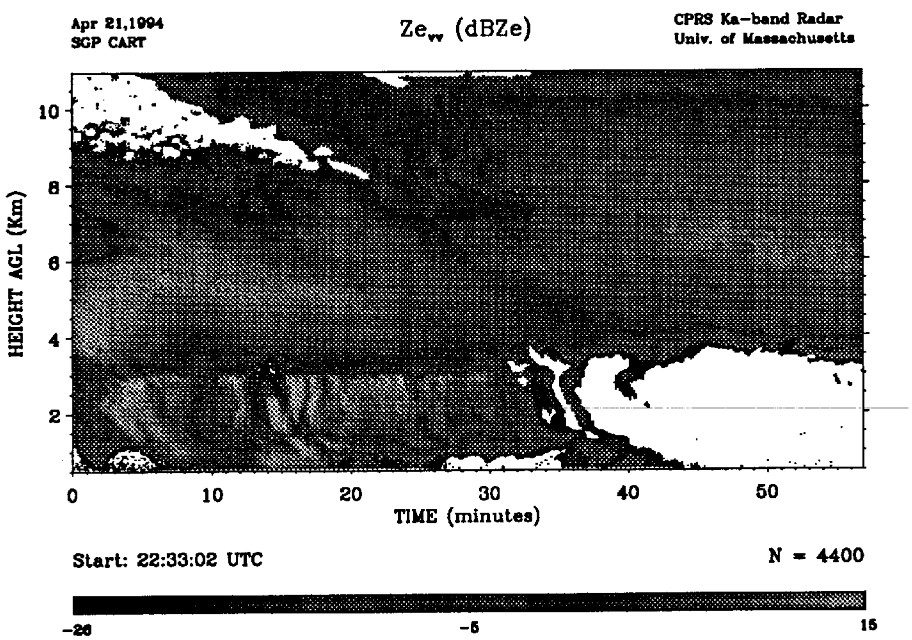
Although much has been learned from independent radar and lidar studies of precipitation, occasionally supported by aircraft profiling, what has been lacking is combined optical, microwave, and in situ observations of the melting layer. Fortunately, the rainshowers on April 21, 1994, during the Remote Cloud Sensing Intensive Observations Period (RCS IOP) at the Southern Great Plains Cloud and Radiation Testbed (CART) site provided an opportunity for coordinated dual-wavelength University of Utah Polarization Diversity Lidar (PDL, at 0.532 and 1.06 μm), University of Massachusetts Cloud Profiling Radar System (CPRS, at 9.1 and 3.2 mm) Doppler radar, and University of North Dakota Citation aircraft measurements.

Vertically-pointing PDL and CPRS data were jointly collected from about 2230-2330 UTC on April 21, 1994, as the first of several light rainshowers ahead of a line of thunderstorms drifted over the site. The sporadic precipitation fell from lowering anvil and embedded stratus clouds. At 2310 UTC the Citation began a vertical spiral ascent above the site, and although little rain was sampled in the dry air layer below the freezing level (at 3.9 km), large snowflakes and some mixed-phase cloud conditions were probed up to a height of 6.5 km before the mission was terminated because of data computer problems.

For this 1-hour period, Figure 1a shows 1.06-μm laser backscattering (in arbitrary units based on a logarithmic grayscale), 1b shows 9.1-mm reflectivity factors in dBZe, 1c shows 3.2-mm vertical Doppler velocities V, and 1d shows 9.1-mm linear depolarization ratios (LDRs) (note inserted radar scales). Together, these displays illustrate several classic features of the radar/lidar bright band. However, what is of most interest here is the presence of the previously unreported lidar dark band between 2.8-3.0 km in Figure 1a.

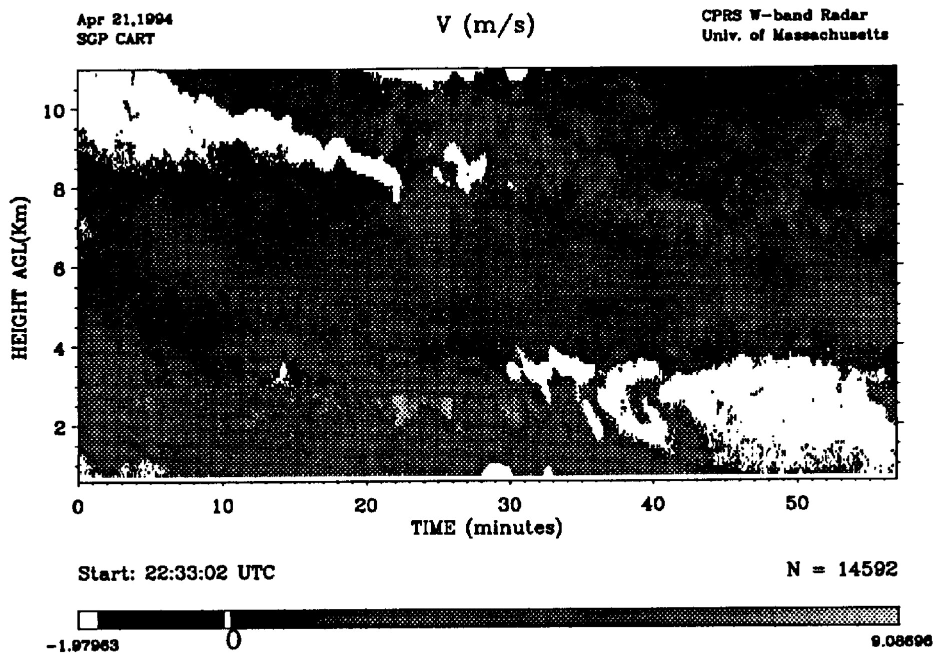


a)

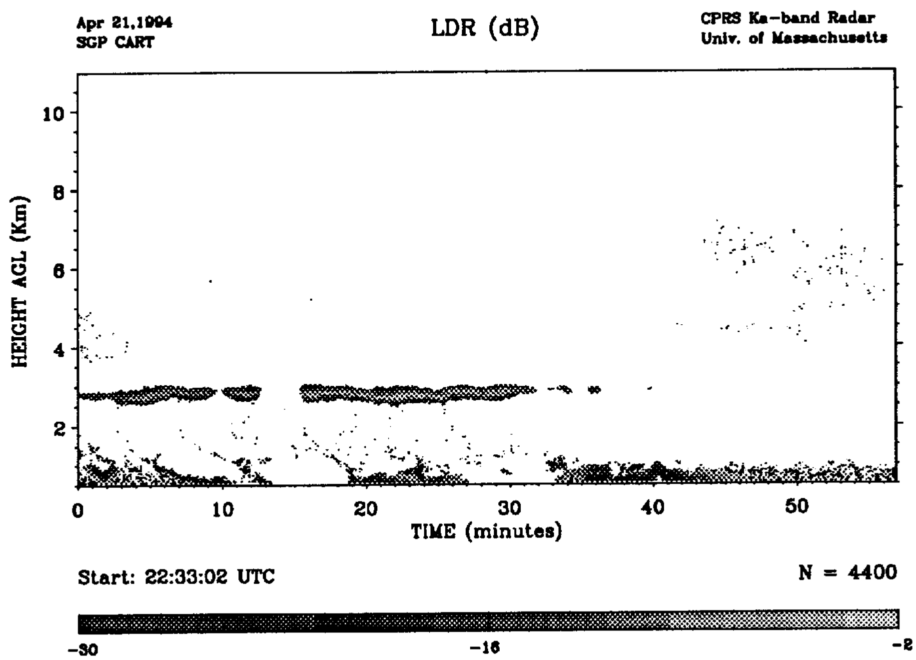


b)

Figure 1. a) Approximately 1-hour height-versus-time plots from the April 21, 1994, RCS IOP case study at the SGP CART site, showing, a 1.06-μm PDL backscattering (note the dark band between 2.8-3.0 km); b) 9.1-mm CPRS radar reflectivity factors in dBZe.



c)



d)

Figure 1 (cont). c) 3.2-mm CPRS vertical Doppler velocity; d) 9.1-mm CPRS linear depolarization ratios.

According to the lidar depolarization data (not shown), the dark band occurs just where the melted snowflake-to-raindrop transition happens. According to previous laboratory studies of melting ice particles suspended in a polarized laser beam (Sassen 1977b), a minimum in parallel-polarized backscattering occurs when the melting ice mass occupies the center of a raindrop; this blocks the strong paraxial reflection off the far drop face. Interestingly, it is at a height of about 3.1 km that the major changes in microwave scattering are seen, such as sudden increases in V and dBZe and the beginning of a gradual LDR increase. In other words, at least in this case (where hydrometeor evaporation appears to have been important) the radar bright band features are associated with inhomogeneous raindrops, not the wetted snowflakes as is usually assumed.

These illustrations of our findings from this unique dataset shed new light on the scattering and microphysical properties of the melting layer and suggest that revisions to our understanding of the radar bright band are in order.

References

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