Comparisons Among Cloud Parameter Estimates Derived from Radar, Infrared-Radiometer, Lidar and Aircraft Measurements

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Introduction

Remote sensing methods to retrieve cloud microphysical and radiative parameters from measurements taken by different remote sensors are an important source of quantitative information about clouds. Most of these methods have been developed during the last few years, and their accuracy is not yet well established. One way of assessing this accuracy is by intercomparing results of cloud parameter retrievals using different methods and instrumentation.

The Arizona-95 experiment provided a good opportunity for such comparisons. During this experiment, the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory (ETL) operated two Doppler radars (K_a- and X-band), a narrow-band IR radiometer (10-11.4µm), and a three-channel microwave radiometer. These instruments were deployed at the experiment hub in Cottonwood, Arizona. The combined data taken by the ETL instruments in the vertical mode were used to estimate parameters of ice clouds, including optical thickness, characteristic cloud particle size, and ice mass content (IMC) using the remote sensing radar-radiometer method described by Matrosov et al. (1995).

The ETL instrumentation was collocated with the High Spectral Resolution Lidar (HSRL) operated by the University of Wisconsin. It is possible from lidar data to retrieve information about cloud extinction and characteristic size of cloud particles (Eloranta and Piironen 1995). Particle sampling from research aircraft provided *in situ* data for comparisons with cloud parameters derived remotely.

Retrieval Results from Radar and Radiometer Measurements

The case of March 3, 1995, provided a good opportunity for comparing cloud parameters retrieved by different remote sensing methods and *in situ* data. University of Wisconsin and ETL instruments were operated side and by side in the vertical mode. Most of the time between 00:00 and 04:30 UTC, a two-layer cloud system existed. Radar-radiometer analysis of data was performed only for the time period between about 2:10 and 4:20 UTC when these instruments were pointed vertically. A thin lower layer at about 4 km contained a small amount of liquid water in addition to ice, and the thick upper layer consisted predominantly of ice particles. Aircraft penetrations accompanied ground-based cloud observations.

Figure 1 shows results of particle size retrieval in the upper cloud layer during the 20-min period when this layer was the thickest. The characteristic sizes of ice particles are expressed in terms of median mass diameters of equal-volume spheres, D_m. The first order gamma size distribution was assumed when making these retrievals. It was also assumed that effective bulk density of cirrus particles decreases with size. The effect of the decrease of particle bulk density with size results in diminishing median mass diameters relative to median volume diameters, D_o. For large characteristic sizes D_m could be less than D_o by about 20%.

Different remote and direct methods provide information on particle sizes expressed in different terms. Effective radii, r_e, mean diameters, D_{mean}, modal diameters, D_{mod} (the size at which the probability distribution reaches its maximum value) are used most often. For the first order gamma distribution used here, the relations between median diameters of equal-volume spheres D_m and other characteristic sizes are the following: $r_e \approx 0.43\ D_m,\ D_{mean} \approx 0.43\ D_m,\ D_{\text{mod}} \approx 0.21\ D_m$.

The distribution of characteristic particle sizes with height shown in Figure 1 is quite typical for many ice clouds observed during this and previous experiments. Very often the largest particles are observed in the lower part of the cloud and the smallest ones are usually concentrated in the vicinity of the cloud top where the concentration of particles is usually the highest.

Comparison of Cloud Properties Obtained from Different Remote Sensors

Comparisons of Infrared and Visible Optical Thicknesses

Retrieval of the absorption optical thickness, τ_{IR}, is a very important part of estimating ice cloud microphysical parameters using the radar-IR radiometer method. τ_{IR} is an important radiative parameter itself, and it is also used in this method to normalize vertical profiles of cloud microphysical parameters. Optical thickness values are estimated from the measurements taken by the vertically pointed PRT-5 radiometer with the wavelength band-width from 10 to 11.4 μm.

The procedure of estimating τ_{IR} accounts for the emission and transmittance of the intervening atmospheric layer, multiple

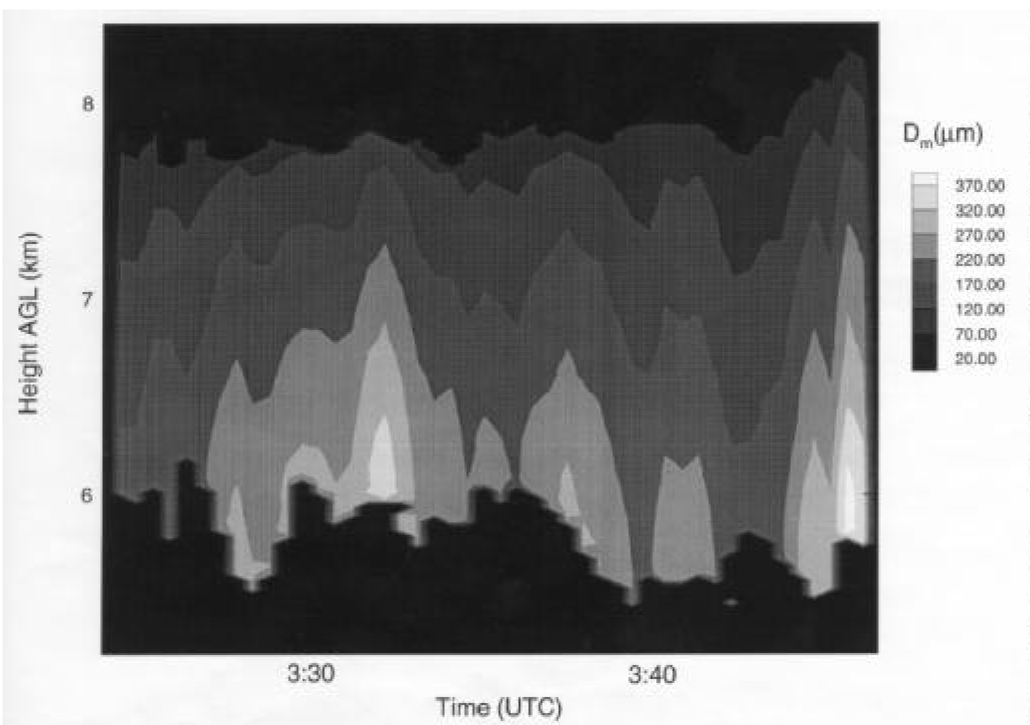

Figure 1. Time height cross section of particle size obtained from K_a-band radar-IR radiometer data. 3/3/95.

scattering of radiation inside the cloud, reflected ground radiation, and changes of cloud temperature with height. HSRL measurements of vertical profiles of visible ($\lambda \approx 0.532$ µm) atmospheric extinction can be used to calculate visible cloud optical thickness, τ_{vis}. For particles that are large compared with the wavelength, one can expect: $2\tau_{IR} \approx \tau_{vis} \approx \tau'_{IR}$, where τ'_{IR} is the extinction infrared optical thickness.

Figure 2 shows comparisons of τ_{vis} derived from HSRL and τ'_{IR} derived from PRT-5. The optical thickness measurement limit for HSRL is 3 and about 5 for PRT-5. $\tau_{vis} > 3$ causes almost complete two- way attenuation of lidar signals and at $\tau'_{IR} > 5$, the cloud thermal radiation is close to the saturation regime. Optical thicknesses greater than these limiting values, 3 and 5, are shown for τ_{vis} and τ'_{IR} , respectively.

As one can see from Figure 3, there are periods of a good agreement between τ'_{IR} and τ_{vis} , e.g., between 3:25 and 4:00 UTC. However, there are also periods when τ'_{IR} is about 40%-50% larger than τ_{vis}, (e.g., 3:10-3:25 UTC and 2:45-2:55 UTC). Some discrepancy can be attributed to different time averaging (30 sec for PRT-5 and 3 min for HSRL) and different apertures (2° for PRT-5 and 0.16 mrad for HSRL). Another possible source of discrepancies is uncertainties of both approaches. Derived values of τ'_{IR} are, for example, quite sensitive to the temperature of the cloud base and cloud temperature gradient, which were estimated from radiosonde soundings.

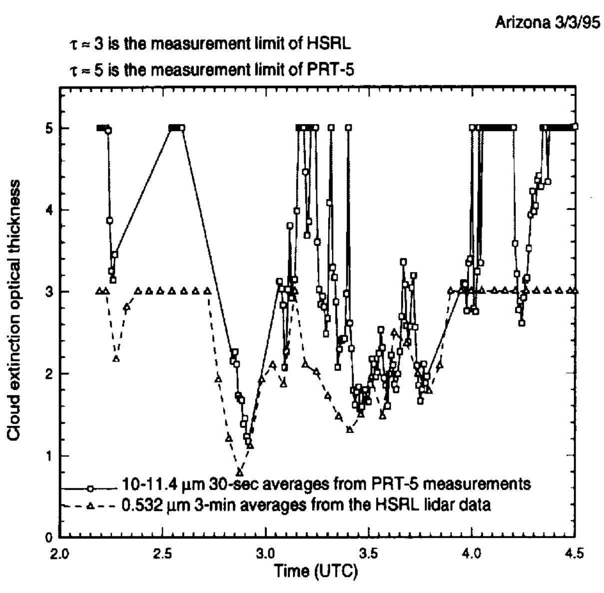

Figure 2. Comparisons of cloud visible and IR optical thicknesses.

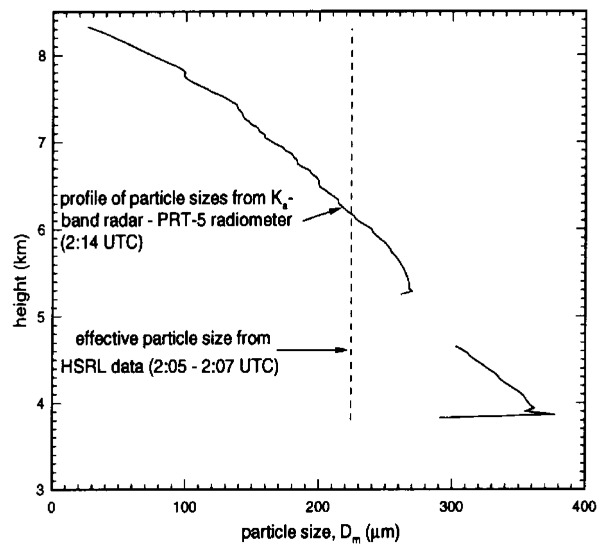

Figure 3. Comparisons of particle sizes obtained from radar-radiometer and lidar measurements.

Comparisons of Cloud Particle Sizes Retrieved from Radar-Radiometer and Lidar Data

Retrievals of particle sizes from HSRL data were made only for one 3-minute period from 2:05 to 2:07 UTC. Size information was derived by matching ratios of lidar returns for different fields of view where the contribution of multiple scattering is present to the lidar return for a 160 µrad field of view and where this contribution is negligible. The best match was obtained for the particle size of 224 µm. The size obtained using this procedure reflects some effective particle size for the considered cloud layer being matched. Some additional calculations are needed to better understand the relation of this size to characteristic particle sizes which are now in common use.

The closest size information from the radar-radiometer data was obtained at 2:14 UTC. Figure 3 shows the retrieved vertical profile of cloud particle sizes from these data. Effective size derived from HSRL data is shown as a dashed vertical line. Note that the size vertical profile is given in terms of D_m . To find a median mass particle size for the whole vertical profile, D^o_m , values of D_m should be averaged through the cloud vertical extend with a statistical weight equal to IMC at each resolution volume. This procedure gives $D^o_m \approx$ 190 µm for this profile from 3.6 km to 8.3 km.

Comparisons of Particle Sizes Retrieved from Radar-Radiometer Data and Aircraft Sampling

Cloud particle sizes were also estimated from 2D samples taken aboard the aircraft during this experimental event. Figure 4 shows comparisons of the size information inferred from the radar-radiometer data and from 2D aircraft measurements. The aircraft data represent mean particle size D_{mean} averaged for the 1-minute period from 3:26 to 3:27UTC when the aircraft was at 4.2 km.The value of D_{mean} from 2D samples is 165 µm. This value may be somewhat overestimated because of the inability of the 2D sampling technique to get reliable estimates of very small particles (< 25 µm).

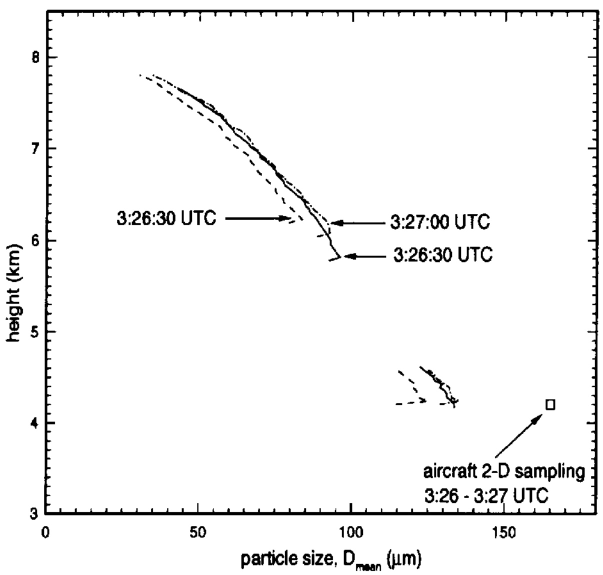

Figure 4. Comparison of particle sizes obtained from radar-radiometer and aircraft 2D data.

Three corresponding particle size profiles retrieved from radar-radiometer data are shown for both cloud layers. For easier comparisons, this information is given in terms D_{mean}, rather than D_m as in previous figures. Comparisons of these three profiles show some variability of particle sizes even during such short time periods as 30 seconds. The values of D_{mean} observed near the cloud base are about 120-135 µm, which compares rather favorably with 165 µm from the 2D spectra.

Conclusions

Comparisons of thermal infrared and visible cloud optical thickness showed that they agree well during some periods, while IR extinction optical thicknesses are somewhat higher than visible optical thicknesses during other periods. Preliminary comparisons also showed a good agreement between particle size information retrieved from K_a-band radar and IR-radiometer measurements, HSRL measurements, and the 2D aircraft *in situ* sampling.

References

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