Variability of Ice Cloud Microphysical Parameters as Revealed by a Remote Sensing Method

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Introduction

The vertical distribution of cloud radiative parameters is important for determining cloud feedback in the climatic system. The radiative parameters of clouds are governed by their microphysical properties such as cloud particle characteristic size and ice water content (IWC).

To improve the representation of clouds in general circulation models, one needs statistical information on typical vertical distributions and variabilities of cloud parameters. Such information can be obtained on a regular basis remotely only with the use of active sensors such as radars. This was one of the main reasons for deploying ground-based K_a-band cloud Doppler radars at different Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed (CART) sites. The first of these new cloud-profiling, K_a-band radars began routine operations at the Southern Great Plains CART site in November 1996.

A justification for deploying the K_a-band cloud radar at CART sites was the long history of successful use of NOAA's K_a-band scanning Doppler radar to observe non-precipitating clouds. This study presents some results of using the NOAA K_a-band radar and the broad-band IR radiometer (10.0-11.4 microns) to retrieve vertical profiles of microphysical parameters related to ice clouds.

The icecloud data sets were collected during the Second ISCCP Regional Experiment (FIRE-II), the Atlantic Stratocumulus Transition Experiment (ASTEX), and the 1995 Arizona Program field experiments. The radar-radiometer method used for microphysical retrievals and approaches for estimating retrieval accuracies are described in Matrosov et al. (1994, 1995).

Variability of Characteristic Size of Cloud Particles

One of the important cloud parameters available from the microphysical retrievals is the characteristic size of cloud particles. As an example of retrievals, Figure 1 shows two scatter plots of the retrieved particle characteristic sizes for two experimental cases: one from FIRE-II and the other from the 1995 Arizona Program. Sizes are expressed in median diameters of equal-volume spheres D_m. The correspondence between D_m and the effective radius r_e, another common characteristic cloud particle size, is $D_m \approx 2.4\ r_e$, for the first order gamma function size distribution function. The plots represent superimposed vertical profiles of retrieved values of D_m. The retrievals were performed with a vertical resolution of 37.5 m and temporal resolution of 30 sec.

The sensitivity of the NOAA K_a-band radar (-30 dBZ at 10-km level) allows retrieval of D_m as small as about $25\,\mu$m; therefore, some cloud regions, especially near the cloud boundaries, could be missed. New CART radars, however, have a higher sensitivity because of a larger antenna size, longer averaging times, and pulse compression techniques (about -44 dBZ at 10-km level). They should be able to detect almost all tropospheric clouds. The vertical limits of the data in Figure 1 coincide with the highest and lowest radar range gates where clouds were detected.

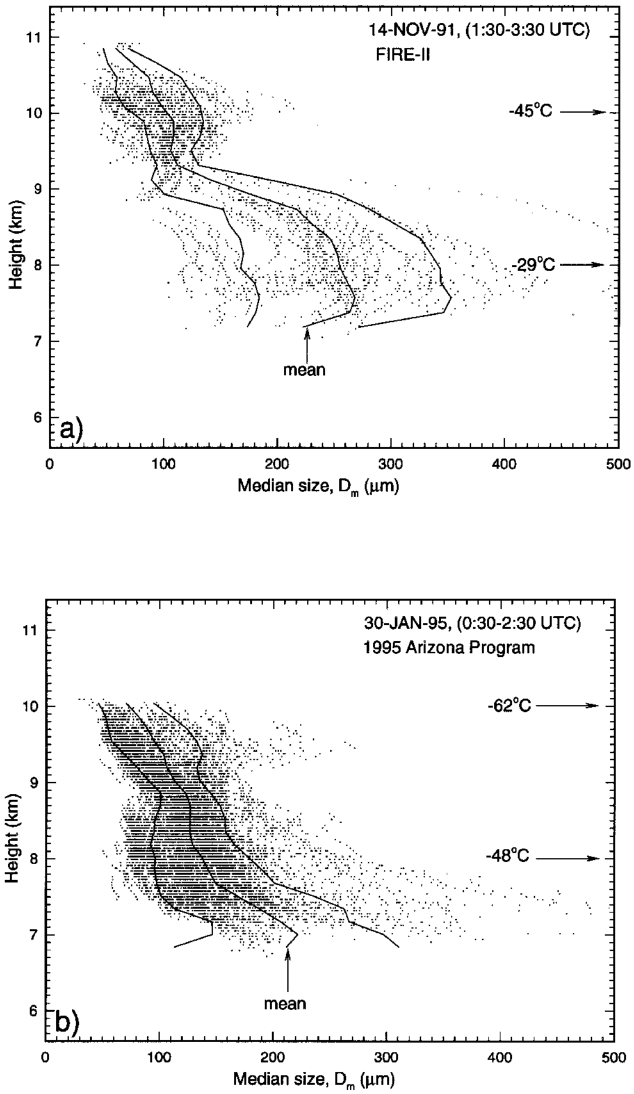

Figure 1. Scatter-plots of Retrieved Values of Cloud Particle Size.

The data presented are rather typical for many processed experimental cases. The middle solid curves in the scatter-plots (Figure 1) show the mean profile of $\bar{D}_m$; the left and right solid curves depict profiles representing $\bar{D}_m \pm$ SD, where SD is the standard deviation. Temperature reference points from nearby radiosonde soundings are shown on the altitude axes. Collocated microwave radiometer measurements indicate that no significant amount of liquid water was present in these clouds. The FIRE-II case (Figure 1a) represents a two-layer ice cloud and the 1995 Arizona Program (Figure 1b) represents a single layer ice cloud.

The mean particle characteristic size generally increases toward the cloud base. However, in a few of the lowest radar range gates, this trend inverses, indicating possible sublimation. Values of standard deviations from mean profiles are generally a factor 2 or 3 smaller than the mean values. However, the vertical variability of $\bar{D}_m$ from smaller particles near the cloud top to larger particles near the cloud base can reach one order of magnitude. The vertical variability in individual profiles of 30-sec duration can be even greater.

Variability of Cloud Water Content

Figure 2 shows the scatter-plots of the retrieved values of IWC (this parameter is sometimes called ice mass content [IMC]) for the same clouds as in Figure 1. The variability of IWC is much greater than that of D_m. This variability can reach several orders of magnitude (up to two orders of magnitude for mean profiles and up to four orders of magnitude for individual profiles). Most of the retrieved IWC values, however, are usually in the range from 0.001 g/m^3 to 0.1 g/m^3, which is in general agreement with aircraft observations of cirrus clouds.

Mean vertical profiles of IWC are depicted in Figure 2 by the left solid curves. Unlike cloud particle characteristic sizes, which tend to increase towards the cloud base, profiles of IWC do not exhibit a consistent pattern. Our experience with the IWC retrievals using different observational cases shows that mean profiles of IWC sometimes show almost neutral vertical distributions with one or several local maxima. In other cases (not shown here), IWC exhibits a tendency to increase toward the cloud top or base.

An important difference between the vertical variability of IWC and the vertical variability of D_m is the relative magnitude of standard deviations from mean profiles. For IWC, values of standard deviations shown as dashed lines in Figure 2 are often close to mean values and sometimes exceed them. Right solid curves in Figure 2 represent the sum of mean and standard deviation values for each observational case.

Estimations of the microphysical retrieval errors were performed both theoretically and by verification with in situ aircraft measurements (Matrosov et al. 1994, 1995). These estimations indicate that retrieval errors of IWC are generally higher than those of D_m. In situ verifications performed with a limited volume of data showed accuracy of about 35% for D_m and about 55% for IWC.

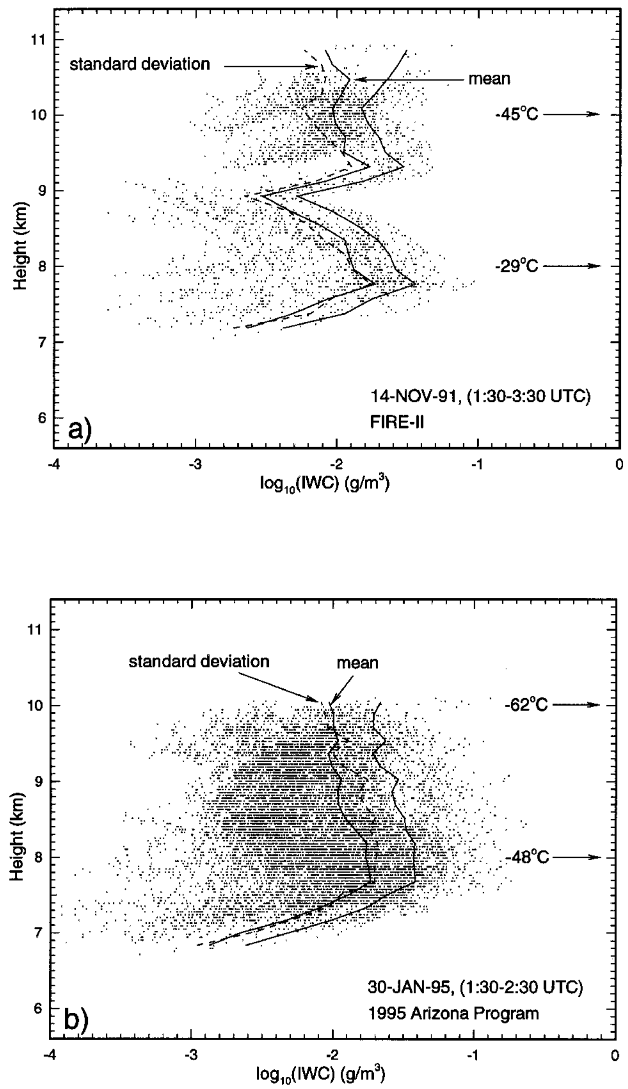

Figure 2. Scatter-plots of Retrieved Values of Cloud IWC.

References

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