Intercomparisons Between Remote and In Situ Measurements of Ice Cloud Microphysics During the Spring 1997 Cloud IOP

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Introduction

The spring 1997 Cloud Intensive Observation Period (IOP) was conducted at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site during April 1997. The objectives of this IOP included comprehensive testing of the Atmospheric Radiation Measurement (ARM) Program's millimeter-wave cloud radar (MMCR) and verifications of several cloud retrieval algorithms by comparisons of the remotely retrieved cloud microphysical parameters with in situ measurements taken directly from aircraft. In addition to the standard SGP site instrumentation, the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory (ETL) K_a-band radar and a Barnes-type PRT-5 IR radiometer were deployed at the CART site for this IOP. The University of North Dakota operated the Citation research aircraft equipped with a two-dimensional cloud (2DC) probe, a one-dimensional precipitation (1DP) probe for sampling ice cloud particles, and the standard Forward Scattering Spectrometer Probe (FSSP) probe for sampling nonprecipitating liquid water clouds. In addition, a video imaging particle system (VIPS) was installed on the aircraft for sampling very small ice cloud crystals that could not otherwise be detected by 2DC probes. A number of cirrus and stratus cloud cases were observed simultaneously with the ETL and standard CART instrumentation when the aircraft was probing these clouds. This paper considers a priority cirrus case that was observed on April 18, 1997.

Retrieval of Cloud Microphysical Profiles

The cirrus event of April 18, 1997, was observed for 1.5 hours around noon local astronomical time. At about 2000 UTC, the vertically pointed radars began seeing a very transparent faint cloud that gradually matured and became almost opaque at about 2045 UTC. In the next 45 minutes, the cloud gradually dissipated. No cloud liquid phase was detected by the CART microwave radiometer, and, according to a radiosonde sounding, no part of the cloud was warmer than -30° C. The ETL profile retrieval method (Matrosov 1997) was applied to the ETL K_a-band radar and infrared (IR) radiometer measurements to obtain vertical profiles of cloud particle median size, ice water content (IWC), and particle concentration.

Comparing broad-band (10.0µm to 11.4 µm) IR radiometer measurements with simultaneous data integrated over this band from the CART atmospheric emitted radiance interferometer (AERI) revealed that ETL IR radiometer readings were (on the order of a few degrees) too "warm". A correction for the ETL IR radiometer data used in the retrievals was introduced to compensate for this disagreement.

Figures 1 and 2 show the time-height cross-sections of the cloud median particle size (given in terms of diameters of equal-volume spheres, D_m) and IWC, respectively. The height and time resolutions of the presented retrieval data

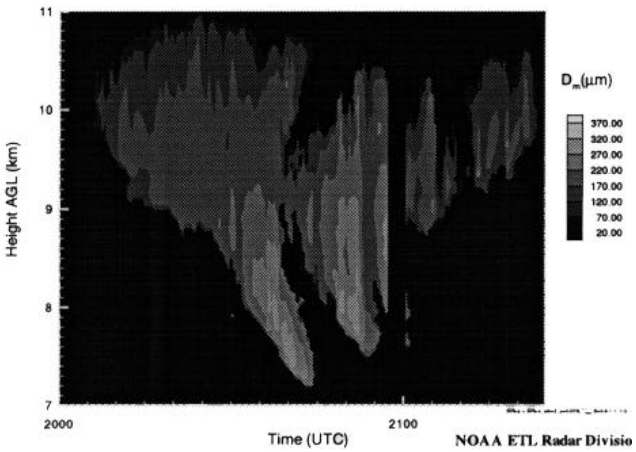

Figure 1. Time-height cross-section of particle size (4/18/97) from the ETL radar-radiometer method.

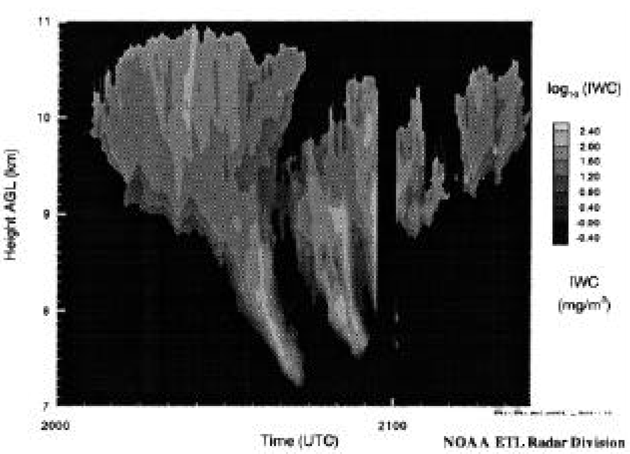

Figure 2. Time-height cross-section of IWC (4/18/97) from the ETL radar-radiometer method.

are 37.5 m and 30 s, respectively. As it can be seen from Figure 1, the characteristic particle sizes were rather small for the most part of the observed cloud. However, two distinctive fall streaks consisting of larger particles (D_m between 200 μm and 300 μm) are seen in the lower part of the cloud. The estimated fall velocities of cloud particles in these fall streaks were between 50cm/s and 70 cm/s. IWC values (Figure 2) were relatively high. These values exceeded 0.01 g/m^3 for most of the cloud.

Comparisons of the Retrieval Results With In Situ Data

The research aircraft sampled the cloud and its vicinity for the whole 1.5 hour period of the case study. During this period, the aircraft made a number of passes approximately over the ground-based instruments. Because of the relatively high temporal variations of cloud microphysical parameters, quantitative comparisons between retrieved and in situ data were made for the 15 passes when the aircraft was within a 3-km diameter circle having its center point directly over the ETL instruments.

Figures 3 and 4 show the comparison results for these passes. The sampled particle sizes did not generally exceed 1 mm, so 2DC data effectively comprised the whole particle distribution at the largest particle limit. The in situ data in Figures 3 and 4 were obtained using the 2-D spectra processing procedure similar to that described by Heymsfield

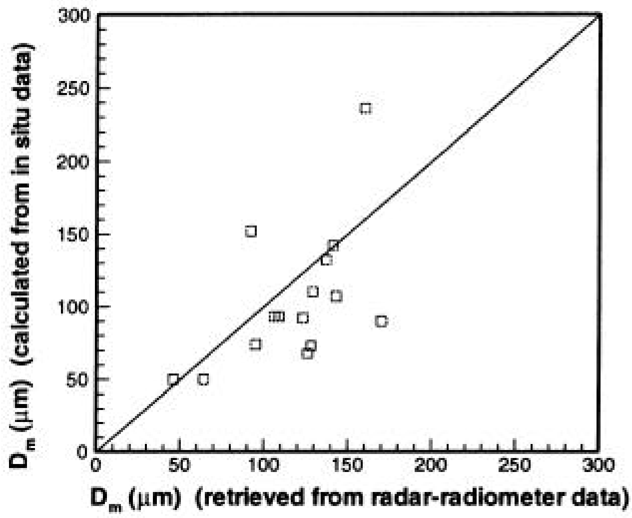

Figure 3. Comparison of median mass particle sizes obtained remotely and from in situ data.

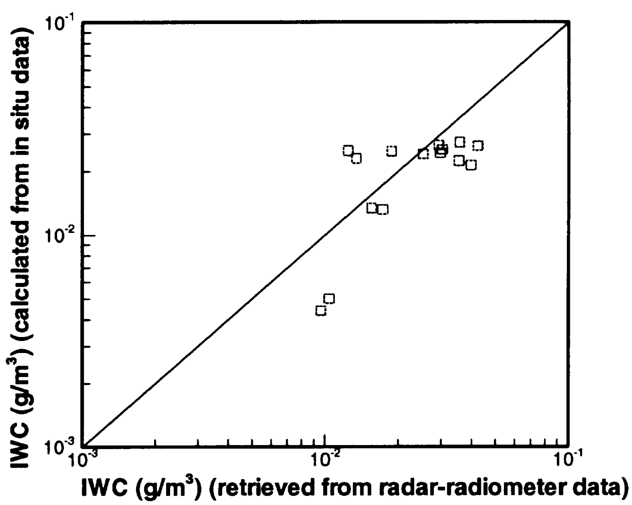

Figure 4. Comparison of cloud IWC obtained remotely and from in situ data.

(1997). The VIPS data were not yet available at the time of the analysis. Although, the inclusion of the VIPS data in the combined in situ results would change comparisons somewhat, this change is not expected to be great since small particles (less than about 20 μm) often contribute little to the total ice mass of a mature cirrus cloud as was shown in the First Intergovernmental Panel on Climate Change (ISCCP) Regional Experiment (FIRE)-II comparisons (Matrosov et al. 1998).

As can be seen from Figures 3 and 4, there is a small positive bias of the retrieved cloud parameters versus their estimates from in situ data. The relative standard deviations between the remote and in situ data sets for this case are about 35% and 45% for the median size and IWC, respectively. Such an agreement is similar to that found for the priority cirrus event from the FIRE-II field experiment (Matrosov et al. 1998).

Comparisons of the Layer-Averaged Retrievals With Different Remote Sensing Methods

The cirrus case of April 18, 1997, provided a good opportunity for comparing two remote sensing techniques to retrieve vertically averaged cloud particle sizes and vertically integrated IWC [i.e., ice water path (IWP)]. One of these techniques is the short version of the profile retrieval method used above and is described by Matrosov et al. (1992). This technique was used for the data collected with the ETL instruments (i.e., the ETL K_a-band radar and the Barnes IR radiometer). The other technique used for this comparisons is described by Mace et al. (1997) and was used with the data from standard CART instrumentation (i.e., MMCR and AERI). Both techniques used the water vapor estimates derived from CART microwave radiometer data.

Although these techniques have much in common in their theoretical background, they differ in details and types of passive measurements used. Therefore, it was worthwhile comparing them since the technique by Mace et al. (1997) is often used with ARM data and the ETL technique by Matrosov et al. (1992) was used with data from a number of previous field experiments including FIRE-II, the Atlantic Stratocumulus Transition Experiment (ASTEX), and Arizona-95. The side-by-side comparisons of the reflectivity measurements of the ETL K_a-band radar and MCCR revealed about a 3-dB bias, MMCR data being lower. In order to make the comparisons meaningful, this 3-dB bias was subtracted from the ETL radar data.

Figures 5 and 6 show comparisons of the layer-averaged particle median sizes and IWP retrieved with these two techniques. The time resolutions of the data obtained with the ARM and ETL techniques are about 7.5 minutes (which was dictated by AERI sampling) and 30 s, respectively. It can be seen from these comparisons that the retrieval results compare very favorably for the particle sizes and relatively well for IWP (except for one point).

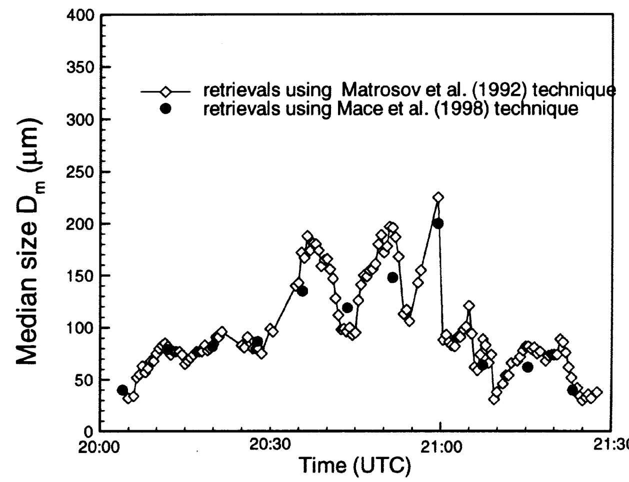

Figure 5. Comparison of layer-averaged cloud median sizes retrieved with two remote sensing techniques.

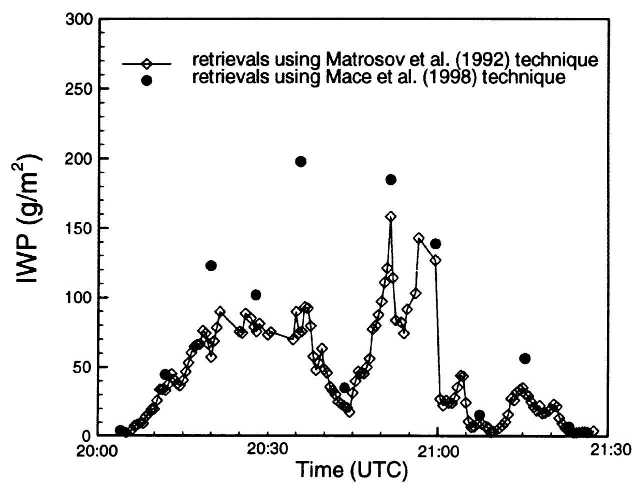

Figure 6. Comparison of cloud IWP retrieved with two remote sensing techniques.

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