P1A.15 GROUND RADAR-BASED ICE CLOUD MICROPHYSICAL RETRIEVALS DURING THE CRYSTAL-FACE FIELD CAMPAIGN

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1. INTRODUCTION

The NOAA Environmental Technology Laboratory deployed its portable cloud observatory (NPCO) at the Eastern ground site near Miami, Florida during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers Florida Area Cirrus Experiment (CRYSTAL-FACE). NPCO consists of a vertically pointing 8 mm cloud Doppler radar (MMCR), an IR radiometer (10.6 -11.3 μm) and a 3 channel microwave radiometer (20.6, 31.6 and 90 GHz). The NPCO was operational for 95% of the duration of the field campaign (July 2002). The measured radar moments and radiometer brightness temperatures were posted on the web in near real-time. In this study, a mutual consistency of different ETL retrievals is analyzed and a preliminary statistical results on retrieved cloud microphysics is given.

2. RETRIEVAL METHODS

A suite of retrieval methods was developed at ETL for estimating vertical profiles of radiatively important cloud microphysical parameters such as particle characteristic size (e.g., the median volume size D_o or the mean size D_{mean}) and water content. For ice clouds, this suite contains 3 different methods. The first, and generally least accurate method, uses empirical relations between measured radar reflectivity, Z_e and the microphysical parameters of interest-D_o , and ice water content (IWC). This method was run in near real time and the retrievals along with measurables were posted on at the ETL web site: www.etl.noaa.gov/programs/2002/fireface/data/

The other two methods for retrieving ice cloud parameters use different types of measurements. The radar-radiometer (RR) method uses vertical profiles of Z_e and IR radiometer brightness temperatures (Matrosov 1999). Estimates of the integrated water vapor amount from microwave radiometer data are used to account for the atmospheric background in the IR measurements. The Doppler radar (DR)method uses reflectivity Z_e and the Doppler velocity V_Z profiles (Matrosov et al. 2002).

The applicability ranges of these two methods are different, although they do overlap. The RR-method is applicable to unobstructed and optically semitransparent ice layers and it has a fine temporal resolution (a 1 min resolution is usually used). The DR method is generally applicable to a wider range of observational situations. The DR method is applicable to any ice clouds with no strong vertical air motions. Its temporal resolution is about 20-30 min. This is dictated by the need to average measured values of V_Z, so the residual vertical air motions are small compared to cloud particle fall velocities.

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The estimated retrieval accuracies for both methods are about 30-40% for D_o retrievals and 60-70% for IWC retrievals. These accuracy estimates were obtained from simple theoretical considerations accounting for uncertainties in different assumptions and also from comparisons between retrieved microphysical parameters and their in situ measurements.

An important issue regarding the retrieval methods is their consistency. Since different methods use different sets of measurements for retrievals, comparing the retrieval results is instructive and provides some assessment of the retrieval uncertainties. Although the method consistency needs to be studied statistically based on long-term retrieval data sets, some concrete examples are nevertheless helpful. Figure 1 shows retrieval results of median voume size D_o for July 24, 2002.

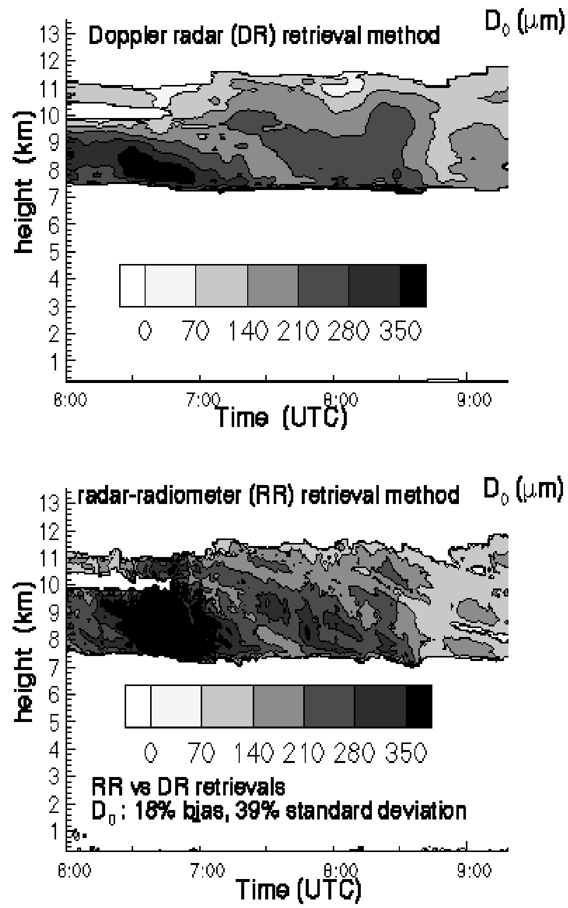

Figure 1. Retrievals of D_o using different methods

For this cloud, median particle size values from the RR method are biased high by only 18% compared with the results of the DR method. This is good agreement considering that completely independent information is used by both these methods to retrieve D_o (i.e, V_Z for the DR method and Z_e and the IR brightness temperatures for the RR method).

Figure 2 shows retrieval results of IWC for this case.

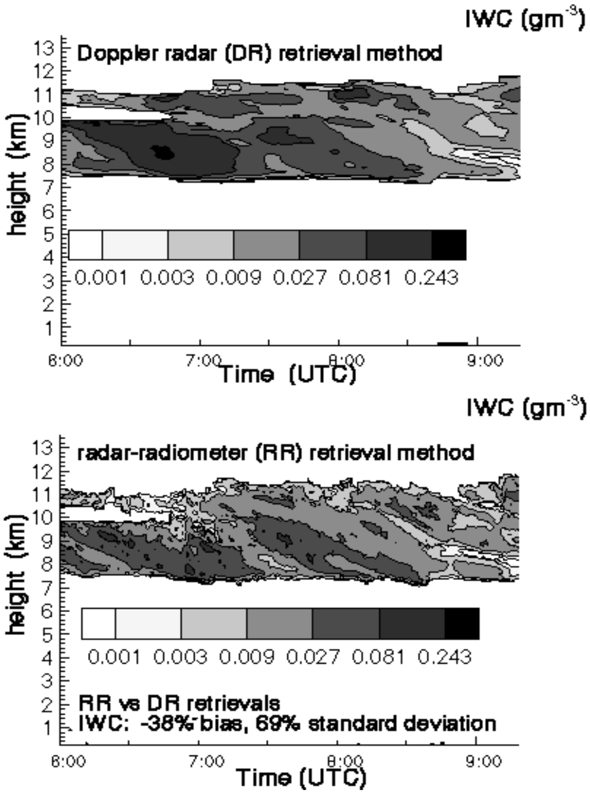

Figure 2. Retrievals of IWC using different methods

The DR method provides larger IWC values compared to the RR method. In part, this difference is due to lower values of D_o from the DR method since for a given measurement of Z_e:

$$\mathrm{IWC} = Z_e\, G^{-1}\, D_o^{-3}\,, \qquad (1)$$

where the coefficient G depends on the particle density and size distribution type assumptions. One explanation of these differences is that some residual upward motions in the mean values of V_z cause underestimations of D_o retrievals from the DR method. Even with these differences, however, the standard deviations between the results obtained with both methods (69% for IWC and 39% for D_o) are within expected retrieval uncertainties.

The ETL retrieval methods provide estimations of cloud optical depth, τ , and vertical profiles of the extinction coefficient, α .The RR method retrieves τ from radiometric measurements and radar cloud boundaries. Optical depth estimates are possible up to $\tau \approx 5$. The DR method retrieves profiles of α from Z_e and V_Z with an assumption about relations between particle area, mass, and size. Optical thickness τ is then calculated as a vertical integral of α

Figure 3 depicts retrievals of τ from both methods for the cloud shown in Fig.1. The agreement is generally good, except in the optically thickest part of the cloud observed between 6:30 and 7:30 UTC. The radiometer-based estimates of τ are known to be progressively less accurate when τ exceeds about 3 (i.e, the cloud is nearily opaque).

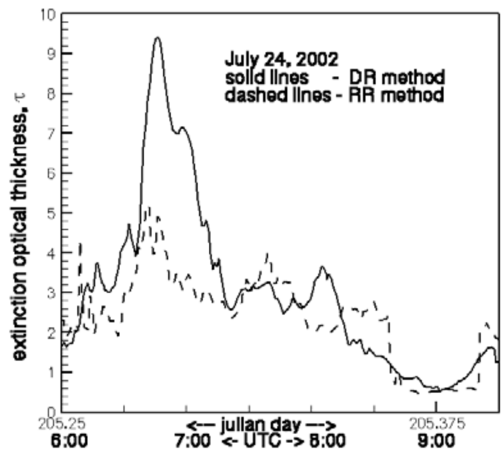

Figure 3. Optical thickness retrievals

3. CIRRUS ANVIL PROPERTIES

Preliminary analysis of the cloud microphysical retrieval results observed during CRYSTAL-FACE indicates that cirrus anvils typically contain larger particles, higher IWC, and thus higher extinction coefficients compared to synoptically-generated cirrus clouds. Examples of a normalized statistical distribution of mean particle size ($D_{mean} \approx D_o/3.5$ for an exponential size distribution) for anvil and non-anvil cirrus are shown in Fig 4. It can be seen that particle populations with D_{mean}>50μm are more likely to be found in anvils.

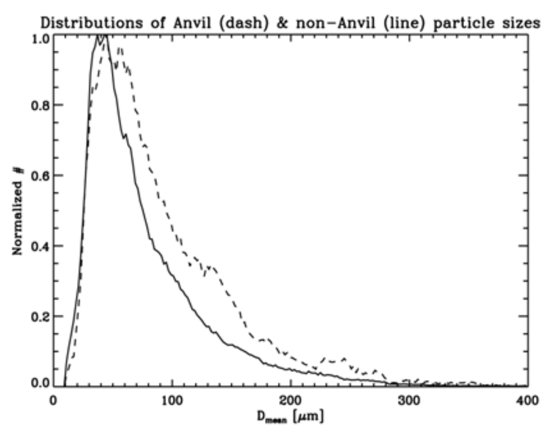

Figure 4. Normalized distributions of D_{mean}

Figure 5 shows a two-dimensional distribution of D_{mean} with height. Different shades of gray represent different intervals of the normalized probability distribution function (pdf), with lighter shades corresponding to higher probabilities. Such distributions can be used to statistically evaluate cloud model performances and assess the appropriateness of different cloud parameterizations in climate models. At any given height, the pdf is quite wide, indicating limitations of using cloud temperature/height to directly prescribe cirrus particle characteristic sizes as some models assume.

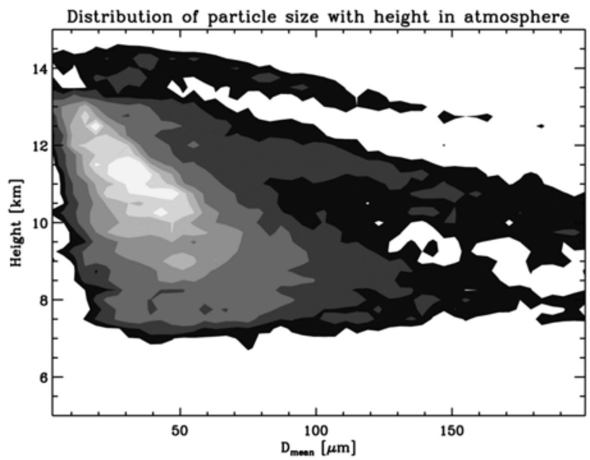

Figure 5. Two-dimensional pdf of D_{mean} in cirrus

Averaged, vertically-normalized profiles of particle mean size obtained using different retrieval methods are shown in Fig.6 (the DR method results are denoted as the radar moments data and the radar empirical curve corresponds to the results from the Z_e only retrievals).

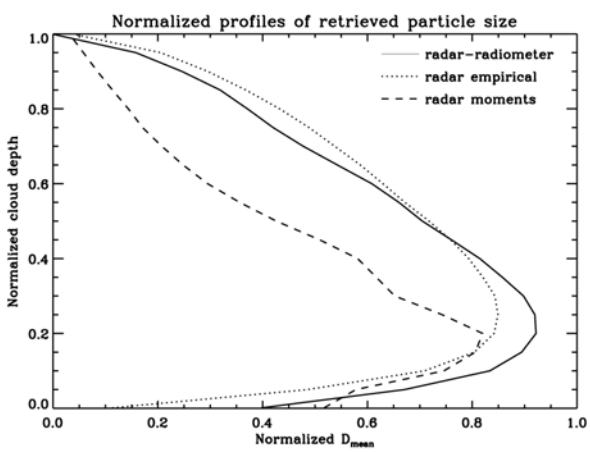

Figure 6. Normalized vertical profiles o f D_{mean}

The results from all three retrieval methods are quite similar indicating a maximum at the normalized cloud depth of 0.2 from the base. The DR method, however, shows more variability than the other methods in the location of this maximum between different profiles. This is indicated by a lower value of the normalized particle mean size. It can also be seen from Figs.5 and 6 that characteristic particle sizes generally increase towards the cloud base , except the nearest vicinity of the base where sublimation processes take place.

Figure 7 shows mean normalized vertical profiles of cloud extinction coefficient.

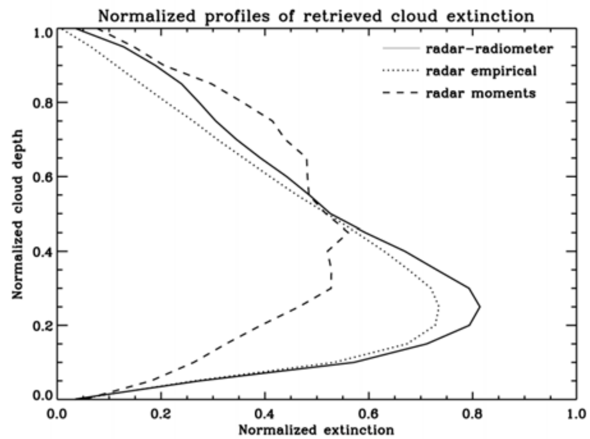

Figure 7. Normalized vertical profiles of extinction

As in Fig. 6, the profiles derived with the RR method and those from the empirical Z_e-based relations are quite similar. This similarity is because the RR method also uses reflectivity data for vertical profiling, however, the radiometric information is used in this method (unlike for the empirical relations) for absolute normalization of cloud parameters. Mean anvil properties are summarized below.The values are based on preliminary analysis of the data from all 3 methods.

	mean	standard deviation
Mean particle size (μm)	110	100
Ice water content (g m^{-3})	0.06	0.2
Ice water path (g m^{-2})	85	110
Extinction coefficient (km^{-1})	1	2

4. CONCLUSIONS

The preliminary analysis of the cloud retrieval results from CRYSTAL-FACE indicates a general mutual consistency between the ETL ice cloud retrieval methods. This encourages a confidence in retrieved cloud products. Future work will include further studies of method uncertainties under different conditions, comparisons with in situ data and with other techniques that use different measurements (e.g., lidar).

References

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Matrosov, S.Y., A.V. Korolev, and A.J. Heymsfield, 2002: Profiling cloud ice mass and particle characteristic size from Doppler radar measurements. *J. Atmos. Oceanic Technol.,* **19**, 1003-1018.