Retrieval of Microphysical and Radiative Parameters of Stratus Clouds in the Second ARM Enhanced Shortwave Experiment (ARESE II)

R. T. Austin, S. L. L' Ecuyer, and G. L. Stephens
Department of Atmospheric Science
Colorado State University
Fort Collin, Colorado

S. D. Miller
Naval Research Laboratory
Monterey, California

Introduction

The Second Atmospheric Radiation Measurement Enhanced Shortwave Experiment (ARESE II) was conducted at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site near Lamont, Oklahoma in February-April 2000. Measurements by the Jet Propulsion Laboratory (JPL)/UMass Airborne Cloud Radar (ACR) (Sadowy et al. 1997) and the Colorado State University Scanning Spectral Polarimeter (SSP) (Stephens et al. 2000) collected during selected ARESE II cases have been used in retrievals of stratus cloud microphysical parameters. The ACR measures cloud reflectivity at 95°GHz; the SSP measures upwelling radiance and fluxes in the visible and near-infrared wavelengths. The instruments were deployed on a Twin Otter aircraft and flown over a number of stratus decks that were present in the area of the SGP site.

Retrieval Algorithm

The stratus retrieval (Austin and Stephens 2000) uses radar reflectivity and visible optical depth to retrieve particle size and liquid water content. The retrieval is structured using the estimation-theory formalism of Rodgers (1976) and later works. This formulation requires explicit specification of input uncertainties and allows the inclusion of a priori information and uncertainty. It provides quantitative measures of uncertainty in the retrieved values and the relative influence of measurements and a priori data.

The forward model assumes a lognormal size distribution of non-drizzle cloud droplets:

$$N(r) = \frac{N_T}{\sqrt{2\pi}\sigma_{\log} r} \exp\left[\frac{-\ln^2(r/r_g)}{2\sigma_{\log}^2}\right],$$

where N_T is the droplet number density, r is the droplet radius, r_g is the geometric mean radius, and σ_{log} is the natural logarithm of the geometric standard deviation. The liquid water content and effective radius (r_e) are defined in terms of moments of the size distribution.

Using an estimation theory approach (Rodgers 1976, and later works), we retrieve a state vector consisting of a geometric mean radius profile and a constant value of N_T. We let N_T and σ_{log} be constant through the cloud column, similar to Frisch et al. (1995); we also specify the value of σ_{log} based on a database of cloud microphysical data. The retrieval algorithm obtains an optimal solution based on measurements, forward model parameters, and a priori data, together with specified uncertainties for each of these quantities. Previous applications of the retrieval are described in Austin et al. (2000).

March 3, 2000 Case

The March 3, 2000 case featured a thin and occasionally broken stratus layer with no evidence of drizzle. Retrieval input data (Figure 1) include ACR reflectivity and visible optical depth derived from 583 nm SSP radiances (Miller et al. 2000). A priori and forward model parameters were based on Miles et al. (2000) statistics: $r_g = 3.6 \pm 1.88$ μm, $N_T = 231 \pm 219$ cm^{-3}, and $\sigma_{log} = 0.39 \pm 0.087$. The radar noise limit was set to -35 dBZ for a multi-bin cloud column and -33 dBZ for a single-bin cloud column.

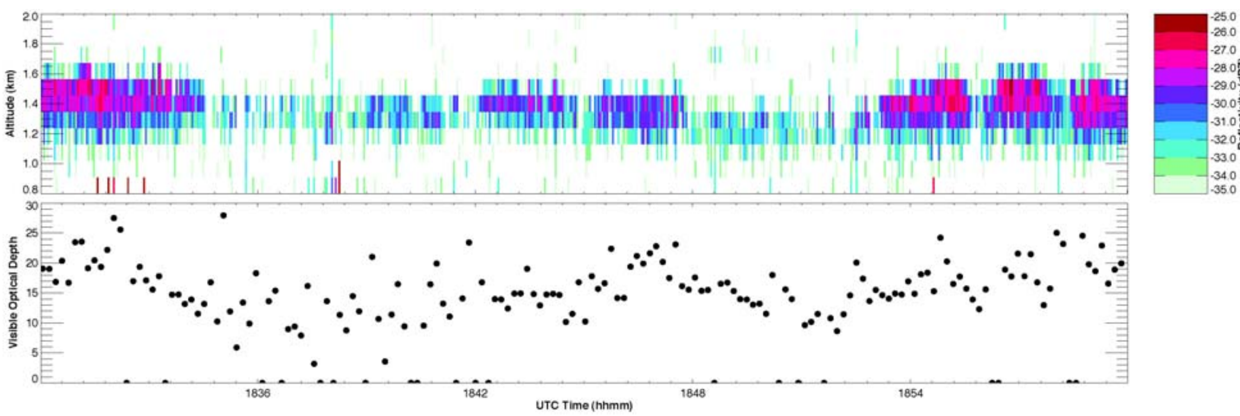

Figure 1. Retrieval input data for the March 3, 2000, stratus case: (from top) ACR reflectivity, visible optical depth.

Retrieved values of liquid water content (LWC), re, and droplet number density, together with A-matrix elements and normalized chi-square fit parameters (diagnostic values) are shown in Figure 2. The fits are generally well behaved, as indicated by the normalized chi-square values that are much less than unity. The retrieved values of r_e are slightly smaller than in situ values measured in the same area (preliminary analysis).

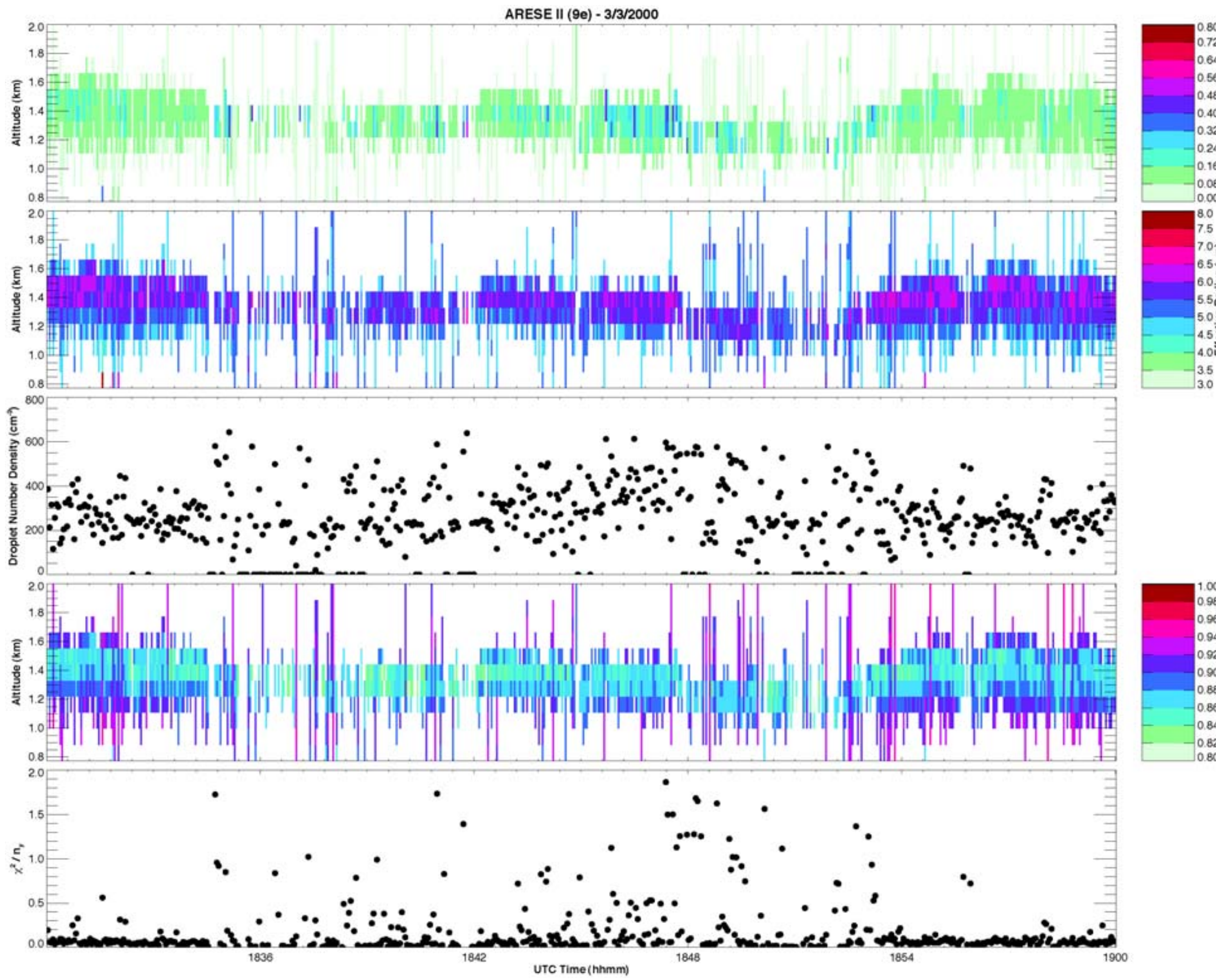

Figure 2. Retrieval outputs for the March 3, 2000, case: (from top) LWC, re, column number density, A-matrix diagonal element, and χ^2/n_y (normalized chi-square). Retrievals with χ^2/n_y greater than 3.0 were discarded (35 of 2297 cases).

March 21, 2000 Case

Much thicker stratus was present on March 21, accompanied by frequent occurrences of drizzle. The retrieval input data are shown in Figure 3. A priori and forward model parameters were again based on Miles et al. (2000) statistics, but different values were used for number density due to the presence of drizzle: $r_g = 3.6 \pm 1.88$ μm, $N_T = 50 \pm 50$ cm^{-3}, and $\sigma_{log} = 0.39 \pm 0.087$. The radar noise limit was set to –35 dBZ for a multi-bin cloud and –33 dBZ for a single-bin cloud, as before.

Retrieved values of LWC, re, and droplet number density, together with A-matrix elements and normalized chi-square fit parameters (diagnostic values) are shown in Figure 4. The fits were much poorer (indicated by the higher normalized chi-square values) due to the presence of drizzle, which is a violation of the assumed drop size distribution. As a result of the drizzle, LWC and number density are underestimated, and r_e is overestimated.

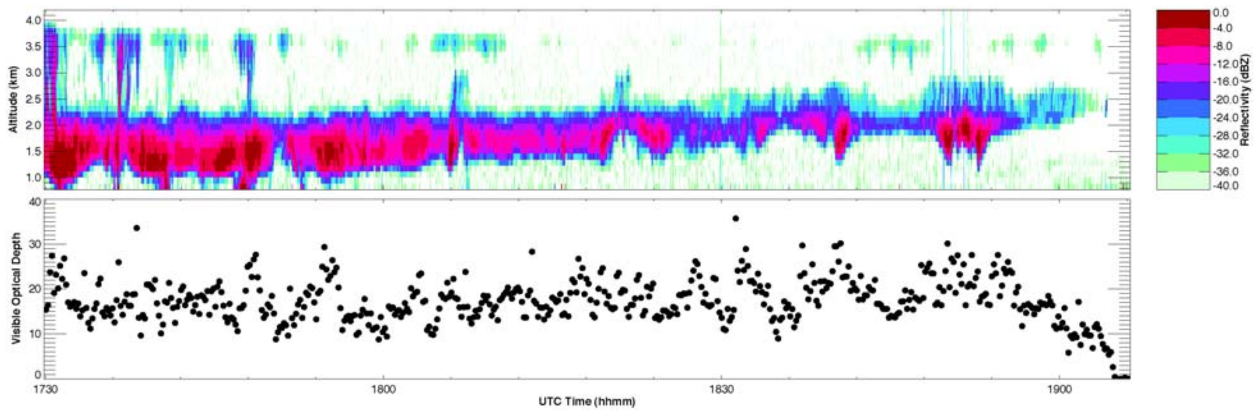

Figure 3. Retrieval input data for the March 21, 2000, stratus case: (from top) ACR reflectivity, visible optical depth.

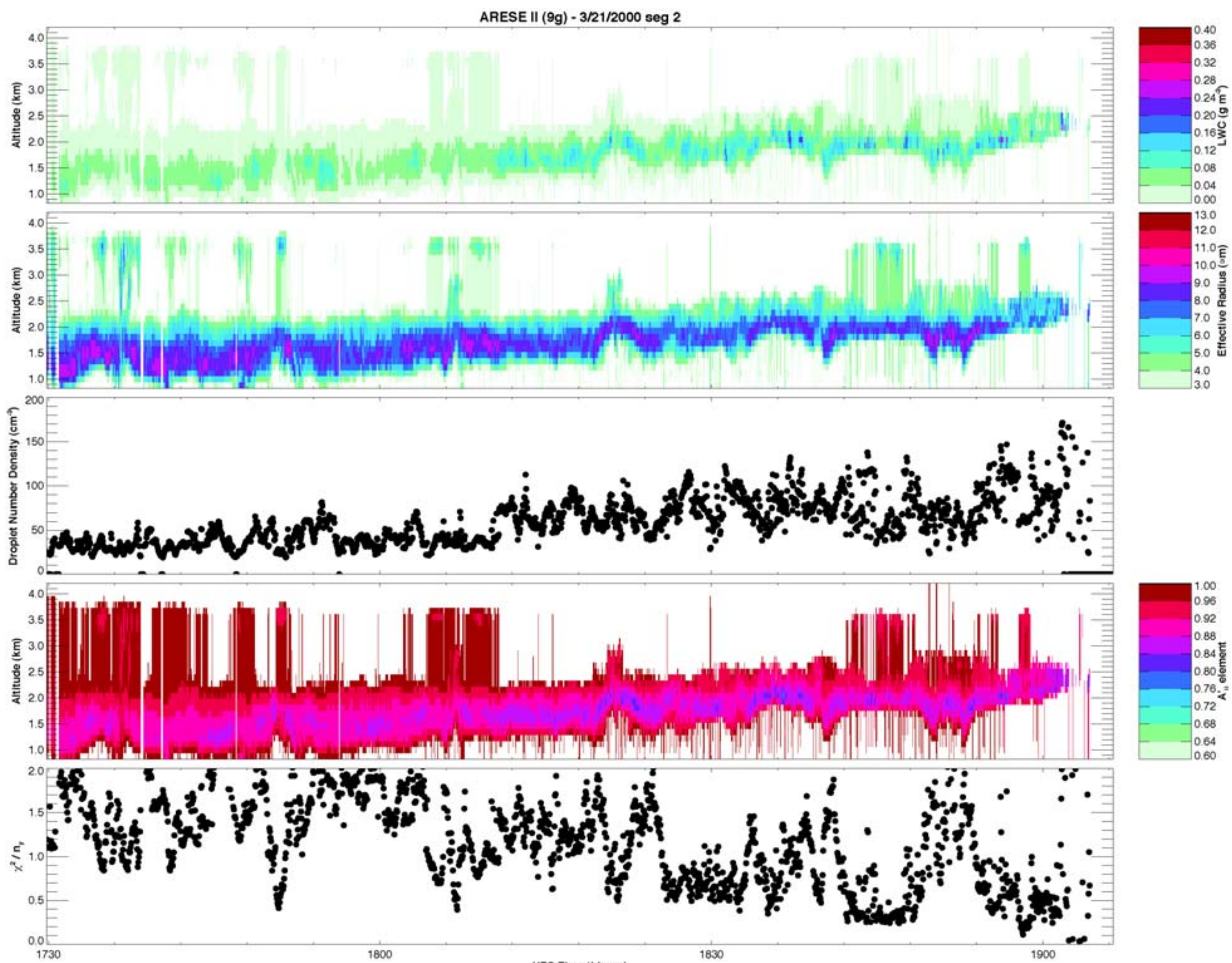

Figure 4. Retrieval outputs for the March 21, 2000, case: (from top) LWC, re, column number density, A-matrix diagonal element, and χ^2/n_y (normalized chi-square). Retrievals with χ^2/n_y greater than 3.0 were discarded (13 of 1876 cases).

March 29, 2000 Case

The March 29 case had substantially higher reflectivities (Figure 5), indicating heavier drizzle or light rain. While the current retrieval is not suitable for such conditions, L'Ecuyer and Stephens (2001) have developed an estimation theory retrieval for light precipitation using 94 GHz radar and (optionally) a liquid water path constraint. Four sample precipitation profiles (not from the ARESE II dataset) are indicated in the plots in Figure 6 by the solid black lines. Corresponding reflectivity profiles are shown in Figure 7. Retrieved profiles of rain rate for the four cases are shown using the liquid water path (LWP) constraint with various levels of uncertainty.

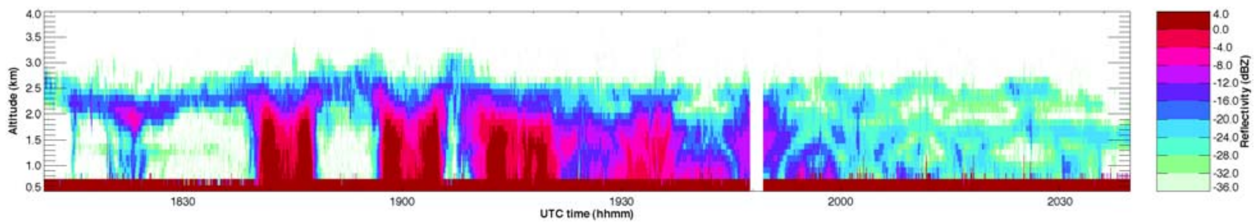

Figure 5. Measured ACR reflectivity for the March 29, 2000, case. A retrieval was not attempted due to the presence of heavy drizzle/light rain.

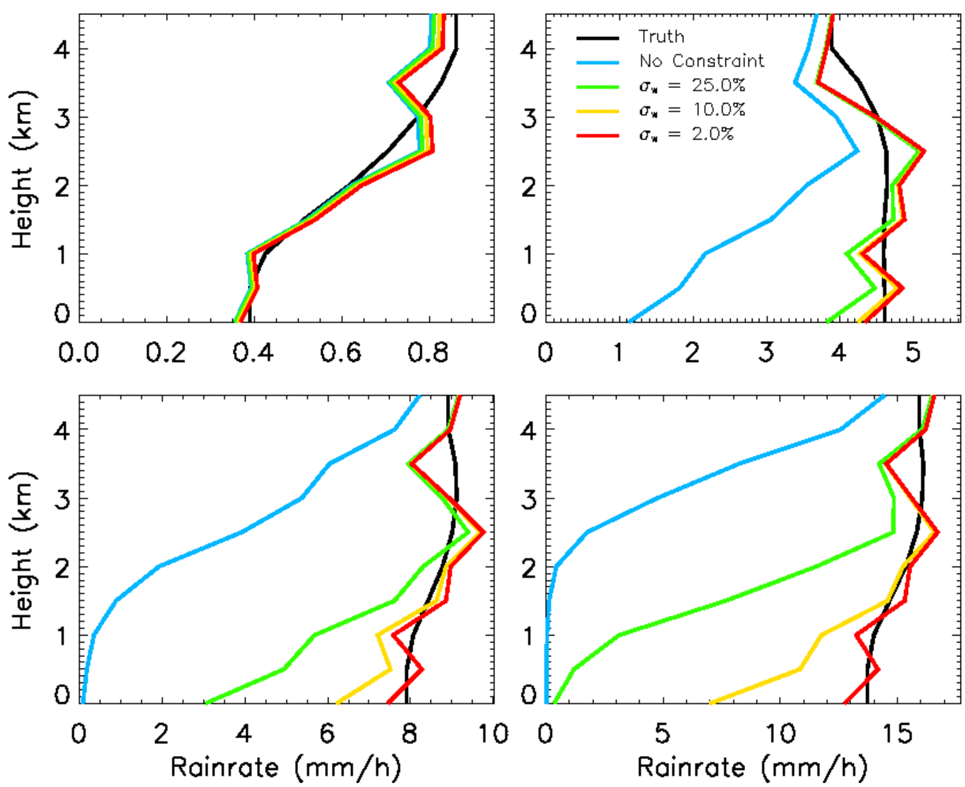

Figure 6. Four sample precipitation profiles together with retrieved profiles using LWP constraints with various levels of uncertainty (method of L'Ecuyer and Stephens 2001).

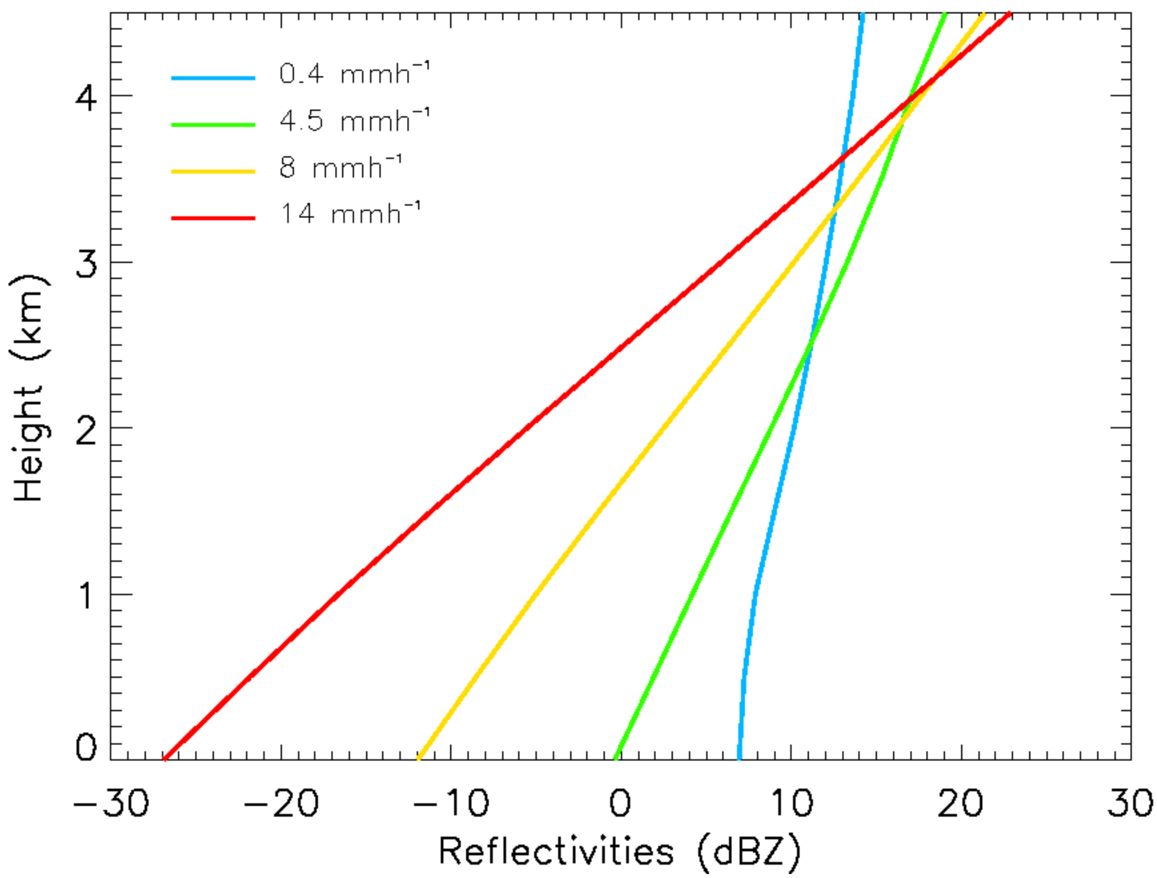

Figure 7. Reflectivity profiles corresponding to the precipitation profiles in Figure 6.

Remarks

Work is in progress to refine these algorithms for the drizzle-free case and to extend the retrieval to the light drizzle case of March 21 and to the heavy drizzle/light precipitation case of March 29 incorporating the method of L'Ecuyer and Stephens. Work is also in progress to test the retrieval using in situ aircraft data from the March 3 and March 21 cases and to incorporate the detailed retrieved cloud properties into the CSU Radiation Scheme (version 1.0).

Acknowledgments

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Corresponding Author

R. T. Austin, mailto:austin@atmos.colostate.edu, (970) 491-8587

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