ARM-GCSS Intercomparison Study of Single-Column Models and Cloud System Models

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The ARM-GCSS Intercomparison Study of Single-Column Models and Cloud System Models

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Introduction

The Single-Column Model (SCM) Working Group (WG) and the Cloud Working Group (CWG) in the Atmospheric Radiation Measurement (ARM) Program have begun a collaboration with the GEWEX Cloud System Study (GCSS) WGs. The forcing data sets derived from the special ARM radiosonde measurements made during the SCM Intensive Observation Periods (IOPs), the wealth of cloud and related data sets collected by the ARM Program, and the ARM infrastructure support of the SCM WG are of great value to GCSS. In return, GCSS brings the efforts of an international group of cloud system modelers to bear on ARM data sets and ARM-related scientific questions. The first major activity of the ARM-GCSS collaboration is a model intercomparison study involving SCMs and cloud system models (CSMs), also known as cloud-resolving or cloud-ensemble models. The SCM methodologies developed in the ARM Program have matured to the point where an intercomparison will help identify the strengths and weaknesses of various approaches. CSM simulations will bring much additional information about clouds to evaluate cloud parameterizations used in the SCMs. CSMs and SCMs have been compared successfully in previous GCSS intercomparison studies for tropical conditions. The ARM Southern Great Plains (SGP) site offers an opportunity for GCSS to test their models in continental, mid-latitude conditions. The Summer 1997 SCM IOP has been chosen since it provides a wide range of summertime weather events that will be a challenging test of these models.

Background on GCSS

The objectives of the GCSS are to: (1) develop the scientific basis for the parameterization of cloud processes, (2) highlight key issues and encourage other relevant programs to address them, and (3) promote the evaluation and intercomparison of parameterization schemes for cloud processes. There are a variety of cloud processes that affect the large-scale behavior of the climate system, but occur on scales too small to be represented explicitly in global numerical models used for climate and weather prediction. Scientists develop numerical representations or parameterizations to represent the behavior of these processes. It is generally recognized that inadequate parameterization of clouds is one of the greatest sources of uncertainty in the prediction of weather and climate. To develop better parameterizations, GCSS efforts are organized into five working groups focused on improving our understanding of the physical processes at work within the following types of cloud systems:

WG 1   Boundary Layer Clouds
WG 2   Cirrus Clouds
WG 3   Extra Tropical Layer Clouds
WG 4   Precipitating Convective Clouds
WG 5   Polar Clouds

The collaboration between ARM and GCSS is facilitated by several ARM Science Team members who are active in GCSS leadership, including the GCSS Chair, and the chairs of WGs 4 and 5. There are also individual collaborations underway within WGs 1 and 2.

The SCM WG is primarily interacting with GCSS WG 4, whose goal is to improve the parameterization of precipitating, convective cloud systems in global climate models (GCMs) and numerical weather prediction models through an improved physical understanding of cloud system processes. The main tool of GCSS WG 4 is the cloud system model, which numerically resolves cloud-scale (and mesoscale) circulations in either two or three spatial dimensions. In contrast, a GCM cannot resolve the individual convective cells or even the accompanying mesoscale circulations. Consequently, the collective effects of these subgrid-scale processes must be parameterized in a GCM. On the other hand, a CSM can determine them directly to the extent that it can accurately represent grid-scale dynamics and the parameterizations of its own sub-grid processes. More information about the current and planned activities of GCSS WG 4 can be found on the web at http://www.met.utah.edu/skrueger/gcss/wg4.html.

The Intercomparison Study

Objectives

In the ARM-GCSS intercomparison study, we seek to provide a common set of forcing data, and other supporting data, for running the SCMs and CRMs. In this way, differences in the results can be attributed to differences in the SCM and CSM parameterizations, and not to the differences in the input data sets. Results from the participating models will be used to address several issues, including the optimal method for obtaining representative results from SCMs via ensemble and "multiple-run" schemes, the isolation of cloud parameterization effects by prescribing the radiative heating, the effects of prescribed surface forcing, and the performance of the SCMs and CSMs themselves.

Between ARM and GCSS WG 4, an estimated 15 SCMs and 10 CSMs are being brought to bear in the case study. The SCMs are simulating all 30 days of the IOP, while the CSMs are simulating selected sub-periods of the IOP. In addition, GCSS WG 1 (Boundary Layer Clouds) is simulating one day (6/19/99) of the IOP where the development of boundary layer clouds is well documented by ARM data (see Figure 6).

Description of Case Study Period

The intercomparison is based on observations collected during an SCM IOP, which covered a 29-day period from 18 June (2330 UTC) to 17 July (2330 UTC), at the ARM SGP Site. This IOP was chosen for the ARM/GCSS case study because it contains a wide range of summertime weather conditions. As illustrated in Figure 1, the IOP was characterized by three distinct weather patterns: (1) the first segment was dominated by local convection and frequent, heavy precipitation, (2) the next segment was generally clear and hot, and (3) the last segment was affected by a large, convective complex with sustained precipitation.
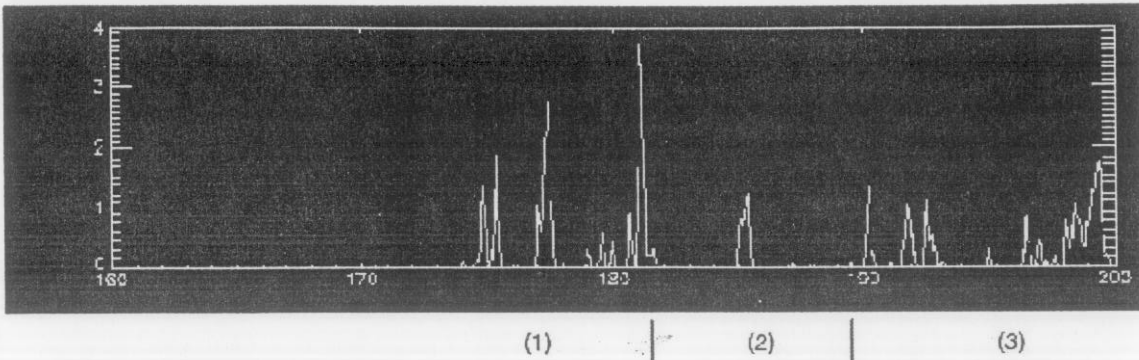
Figure 1: Hourly precipitation rates (mm/hr) over the SGP SCM domain during the Summer 1997 SCM IOP (Julian days 169-199), also known as Case3, as derived from NWS WSR-88D radar data.

Time-height slices of the mean temperature and mean moisture, derived from variational analyses (Zhang and Lin, 1997; Zhang, et al., 1999) of ARM observations, are given as color-filled areas between contours, and the advective tendencies of temperature and moisture, which provide lateral forcings for the SCMs and CSMs, are shown as black contour lines in Figure 2. The diurnal variations in temperature near the surface are evident in Figure 2a, while the moisture variations in response to precipitation events are evident in Figure 2b.
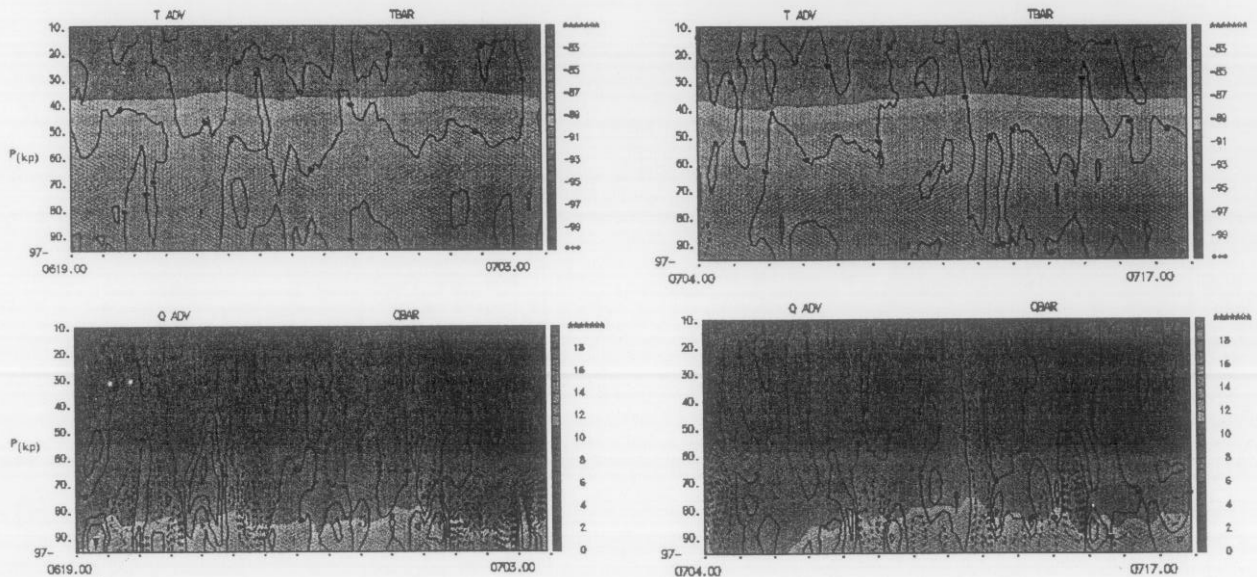

Figure 2: Time-height observations and analyses of (a) mean temperatures in degrees C (colors) and their advective tendencies (lines), and (b) mean water vapor mixing ratios in g/kg (colors) and their advective tendencies (lines) for Case 3, based on Zhang's variational analysis techniques.

Changes in cloudiness over the SGP site during the SCM IOP are documented in Figure 3. Analyses of half-hourly, four-kilometer Geostationary Operational Environmental

Satellite (GOES-8) visible and infrared radiances over the SGP site by the Minnis group at NASA Langley provide profiles of cloud fraction over time in Figure 3a; the white gaps signify missing height analyses or missing data. Given the spatial coverage of the downward-looking satellite, these analyses are best at quantifying the total cloud cover over the entire site. We contrast these cloud fractions with more highly resolved, range-gated estimates from measurements taken by the upward-looking millimeter cloud radar (MMCR) and Micropulse lidar (Figure 3b). While these latter instruments provide much better temporal and spatial resolution than the satellite, they do so within narrow fields of view that may fail to adequately characterize cloud conditions over the entire SGP site. For more details, see the extended abstract by Rodriguez and Krueger at http://www.arm.gov/docs/documents/technical/conf_9903/author.html#R.
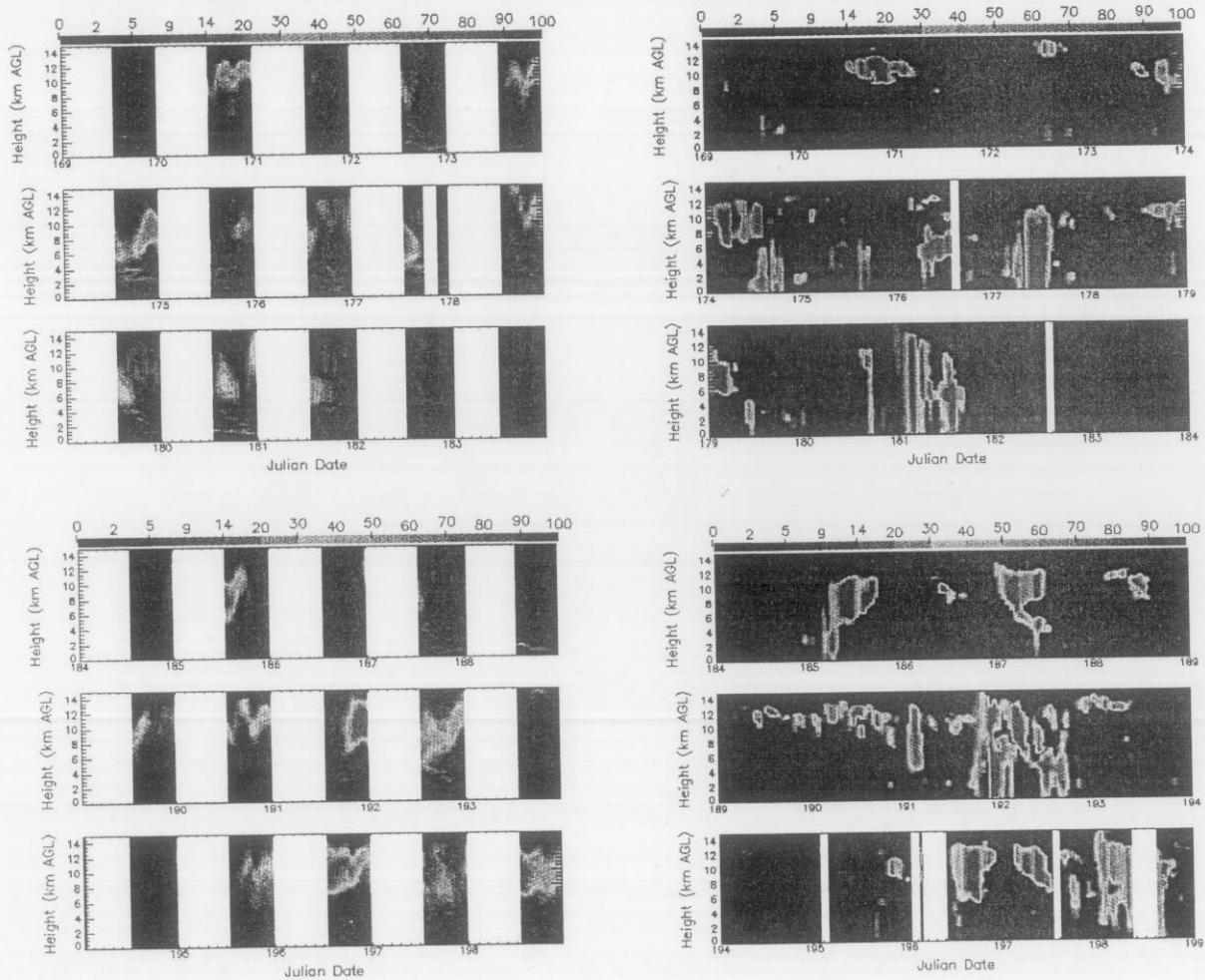

Figure 3: Cloud fractions during Case 3 from (a) averages of CART-wide estimates of cloud heights and cloud thicknesses from Minnis analyses of GOES-8 radiance data, and (b) cloud occurrence frequency analyses of millimeter cloud radar (MMCR) data at the SGP Central Facility.

ARM Cloud Products for ARM-GCSS Collaborations

Several new cloud products, based on ARM data sets, are available to support ARM-GCSS collaborations. For example, vertical profiles of cloud occurrence frequencies for June and July of 1997, derived from MMCR reflectivity data, are illustrated in Figure 4 (provided by Gerald Mace). Cirrus clouds dominate the scene during this two-month period, but a secondary (cloudiness) maximum occurs in the boundary layer.
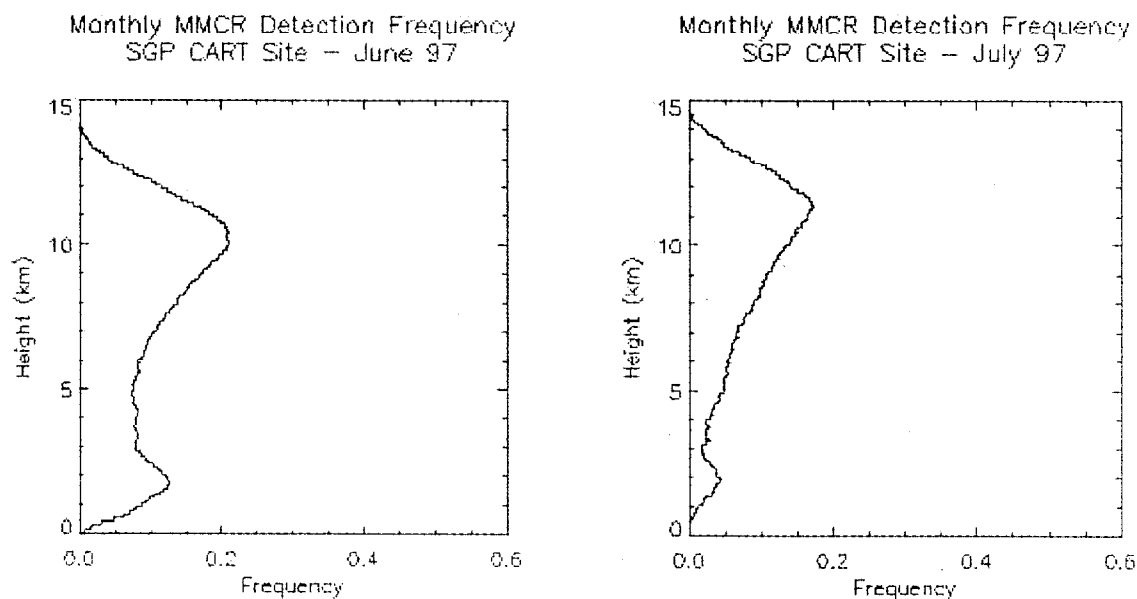

Figure 4: Monthly cloud-detection frequencies at the SGP Central Facility from MMCR data for (a) June, 1997 and (b) July, 1997.

Using published algorithms, adapted to the particular mix of observational platforms at the ARM sites, Mace has combined radar reflectivity measurements from the MMCR with the infrared radiance spectra observed by the Atmospheric Emmittance Radiance Interferometer to derive the layer-averaged microphysical properties of optically-thin cirrus clouds, as illustrated in Figure 5 for June 19, 1997 (Mace, et. al., 1998). Additional examples can be found at
http://www.met.utah.edu/mace/homepages/research/archive/archive.html.

Cirrus Cloud Properties 19 June 1997 SGP CART Site
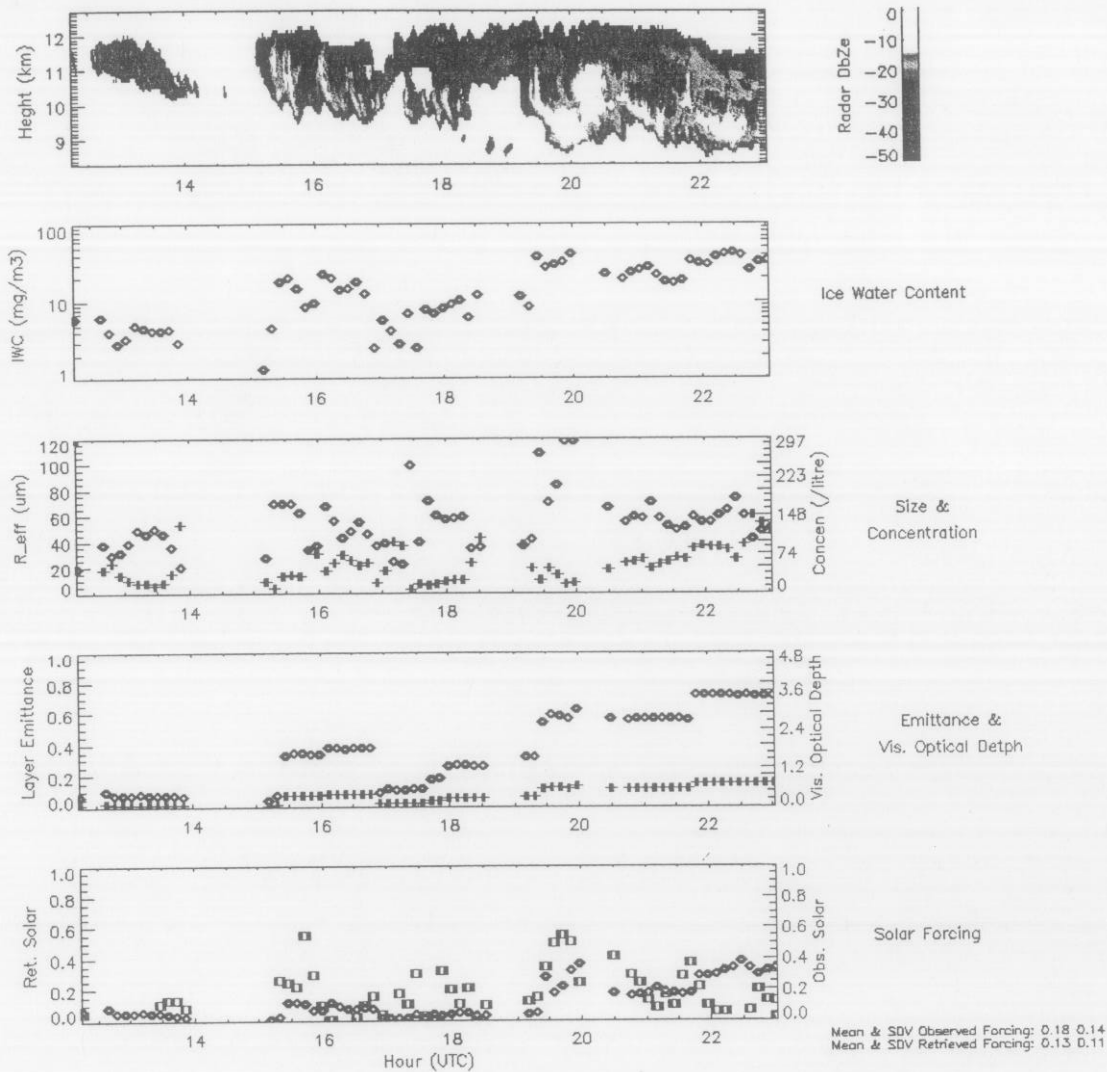Refelctivity Radiance Algorithm

Figure 5: Examples of microphysical retrievals for cirrus clouds at the SGP Central Facility on June 19, 1997: (a) radar reflectivity, (b) ice water content, (c) particle size and concentration, (d) emittance and visible optical depth, and (e) solar forcing (from Mace).

Besides cirrus clouds, the MMCR can do an excellent job of documenting boundary layer clouds, as seen in Figure 6.
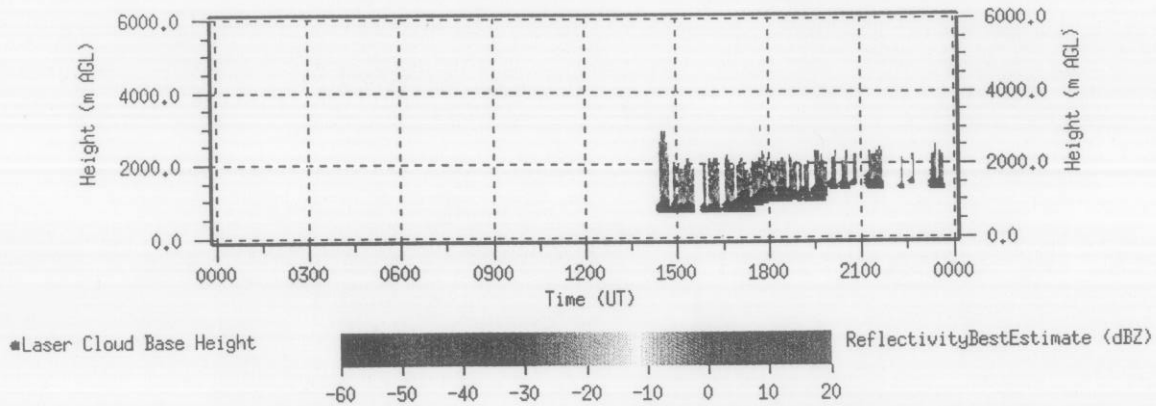

Figure 6: MMCR reflectivities (colors) and ceilometer cloud-base heights (black circles) for SGP boundary layer clouds on June 21, 1997.

However, data collected by the radar within this layer may require additional processing to remove spurious echoes. The generation of "best-estimate" cloud products involves the development and use of algorithms that usually combine ARM data from multiple sources. Figures 7a and 7b show the before and after results from the application of algorithms that use lidar, microwave radiometer and surface meteorological data to remove boundary-layer clutter, which in the summertime is most often caused by insects, from the radar signals (Clothiaux, et. al., 1995).
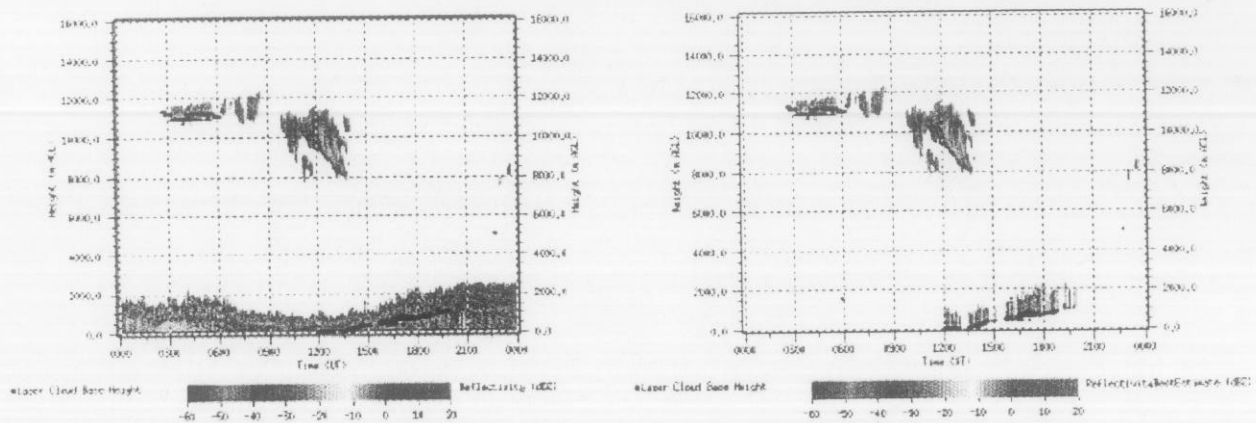

Figure 7: MMCR reflectivities (a) before and (b) after the application of algorithms for the removal of insects and other signal-contaminating objects in the boundary layer.

As exemplified by Figure 8a, images from the Whole Sky Imager provide yet another way of viewing the cloud field. Here, boundary layer clouds are captured through a

"fish-eye" lens, which in this instance is covered by a red filter to enhance the cloud definition (Shields, et. al., 1998). Subsequent processing of the radiance data, collected from a highly-resolved system of pixels, allows an estimate of cloud amounts to be made within chosen sectors. Associated cloud heights for such scenes can be established, based on cloud radar and lidar ceilometer data (see Figure 8b).
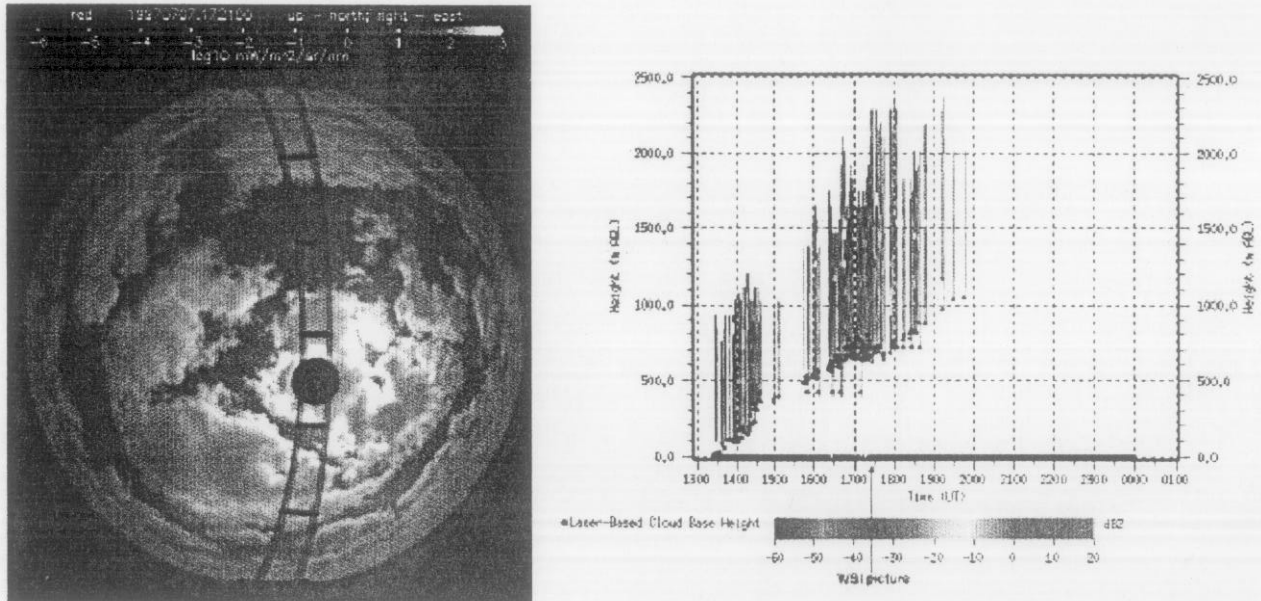

Figure 8: (a) Whole sky image of boundary layer clouds, and (b) cloud heights, as established by MMCR and ceilometer data (arrow points to the time at which the WSI image was taken).

A continuing stream of cloud products, formed from ARM's databases, is being developed. Feedback from ARM and GCSS participants in the intercomparison study will guide the future development and improvement of ARM's cloud products.

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