ARM Value-Added Cloud Products: Description and Status

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Introduction

The Atmospheric Radiation Measurement (ARM) Program operates a variety of state-of-the-art active and passive remote sensors at its sites. These sensors provide information about the thermodynamic state of the atmosphere and the structure of the clouds that are present above the site. Families of value-added products (VAPs) that contain geophysically relevant data are produced from the electronic outputs of these sensors and used by the ARM Science Team and by other members of the atmospheric science community. The selection and production of VAPs is governed by various inter-ARM working groups and the Science Team Executive Committee. This paper describes the VAPs that are being produced for the Cloud Properties Working Group (CPWG) by the ARM infrastructure.

Value-Added Cloud Products

The cloud VAPs can be divided into two groups: core and derivative. At present, the CPWG produces three core VAPs:

1. **Active remote sensing of cloud layers (ARSCL).** This VAP combines the data from the millimeter cloud radar (MMCR), micropulse lidar (MPL), laser ceilometer, microwave radiometer (MWR), and surface measurements. It produces a best estimate of cloud location and radar echo characteristics above the central facilities of each of the ARM sites. The MMCR collects data in four complementary modes, which sample different aspects of the cloud in the column. Data from these four modes are combined and a best estimate of hydrometeor location, effective reflectivity factor,

Doppler velocity, and Doppler spectral width is produced. Because the MMCR is sensitive to large drizzle and rain droplets that lie below the optical cloud base and are not radiatively significant, the MPL is used to identify the optical cloud base. The ARSCL VAP requires human interaction to remove some radar artifacts. An example of ARSCL cloud location and reflectivity output is shown graphically in Figure 1. The temporal and spatial resolution of ARSCL output is 10-seconds and 45 m.

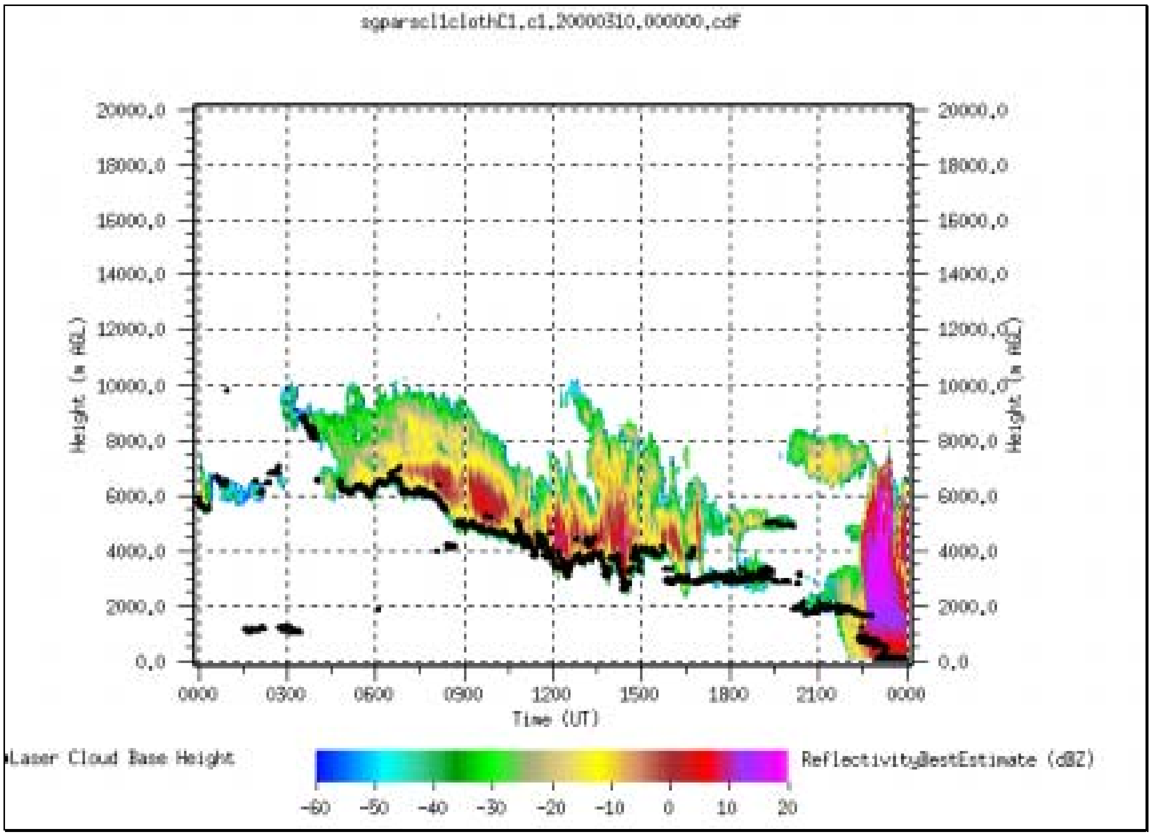

Figure 1. A time versus height cross section of output from the ARSCL VAP for March 10, 2000.

2. **Merged Sounding (MERGED_SOUNDING).** The goal of the Merged Sounding VAP is to produce a best estimate of the atmospheric state in the column above the ARM Central Facilities. The procedure is an extension of an operational atmospheric-state product developed at the University of Utah (Mace, personal communication), but is being modified to be consistent with the ARM Line-By-Line Radiative Transfer Model (LBLRTM) grid spacing. The new VAP has a data flow-down structure beginning with radiosonde data as the first-order estimate of the thermodynamic structure of the column. Additional sources of data, such as the AERI, are incorporated as constraints, when they are available. If radiosonde data are not available from the central facility, data from the nearby Oklahoma City regularly scheduled radiosonde data are used. If the Oklahoma City radiosonde data are not available, model data from Eta, ECMWF, and RUC are used, with Eta data being the first fallback position. Regardless of the source of the input thermodynamic profile for the Merged Sounding VAP, the AERI data are used to estimate the thermodynamic structure in the boundary layer during clear periods.

3. **Microwave Radiometer Statistical Retrieval (MWR_STATISTICAL).** The ARM MWRs measure the atmospheric brightness temperature at 23.8 GHz and 31.4 GHz frequencies. The 23.8 GHz is most sensitive to water vapor emission and less sensitive to liquid water emission. The converse is true at 31.4 GHz. To determine the amount of liquid water in the column, it is necessary to use a radiative transfer model (RTM) to relate the observed brightness temperature from the radiometer to the amount of integrated water vapor and liquid water. A statistical retrieval is constructed by taking years (5-10 years is typically used) of radiosonde profiles of temperature and relative humidity (RH), and adding differing amounts of liquid water when the RH measured by the radiosonde exceeds a predetermined threshold (95% is used by ARM). The resulting ensemble of profiles is used in an RTM to compute a range of theoretically observed brightness temperatures in the two MWR channels. The results of these ensemble calculations are transformed from brightness temperature to opacity, which has a more linear relationship with the integrated water vapor and liquid water content, and a multiple linear regression is performed. The coefficients of this regression are subsequently used to convert the observed opacity to integrated water vapor and liquid water content. At present, the monthly computed statistical absorption coefficients from the RTM are used in the retrieval. Planned improvements include more sophisticated parameterizations for the absorption coefficients, such as regressions to include RH, temperature, and cloud water temperature that are performed on the output of the RTM

These three VAPs represent core information that is used by several other derivative VAPs that produce cloud products for the CPWG. These include:

1. **Microphysical Baseline (MICRO_BASE).** This VAP is part of the broadband heating rate profile (BBHRP) project being conducted within ARM. The BBHRP project produces two heating rate products (see Mlawer et al. 2003 in this volume for details): an instantaneous heating rate profile (PI) and a site average heating rate profile (PA). The BBHRP is a combined effort by all of ARM's working groups (Cloud Parameterization and Modeling Group, CPWG, and Instantaneous Radiative Forcing) to compute a continuous heating rate profile, initially over ARM's Southern Great Plains (SGP) site. One requirement of this project is a continuous survey of the cloud microphysical properties in the column above the site and over the entire Cloud and Radiation Testbed. While there are many sophisticated microphysical retrieval schemes that work under specific cloud conditions, so-called "conditional" retrievals, the BBHRP requirement is for continuous cloud microphysics. The MICRO_BASE VAP was created to fill this need and to provide a backdrop of data that will provide cloud microphysical estimates for those periods in which a conditional retrieval technique is not available. The MICRO_BASE VAP produces two products that are used by the BBHRP: MICRO_BASE_PI and MICRO_BASE_PA. The initial MICRO_BASE products rely entirely on relationships between effective reflectivity factor and water content to determine the LWC and IWC. This enables the retrievals to operate continuously. Input temperatures for the microphysical calculations are taken from interpolated soundings (PI) and the three-hour variational analysis data (PA). Microphysical fields are produced at ARSCL time and height intervals (10 seconds and 45m), and averaged to 20-minute and 45-m resolution for PI and 3-hour and 25 mb pressure intervals for PA. The following parameterizations are used:

Liquid vs. Ice

Reflectivity is divided into liquid and ice contributions. The following unsophisticated initial mixed mode fractionating scheme is used, where T = interpolated sounding temperature at a grid point:

For T < = -16C, assume all ice;
For T > = 0 C, assume all liquid;
For -16 < T < 0 C, ice fraction = -(T - 0) / (0 - (-16)).

Liquid Water Content (LWC), Ice water Content (IWC)

Obtain liquid and ice portions of effective reflectivity factor and apply the Sassen and Liao (1994) and the Liu and Illingworth (2000) reflectivity (Z) to water content relations to obtain liquid and ice water contents. NOTE: for liquid, we assume Nd = 100.

liquid Z = (1 - iceFraction)*totalZ
ice Z = iceFraction * totalZ

LWC = (Nd/3.6 * Z)^1/1.8 g/m^3
IWC = 0.097Z^^0.59 g/m^3

Liquid Mode Radius

The liquid mode radius, r, which is computed using a log normal droplet distribution, is given by

r = (3*LWC / (4*PI*RHOw*N*exp(9*sigma*sigma/2)))**1/3

where PI = 3.14, RHOw is the density of water, and sigma is the width of the distribution (0.35).

Ice Effective Radius

Ice effective radius is computed as a function of temperature, following Ivanova et al. (2001):

ice effective radius = (75.3 + 0.5895T) / 2

Examples of MICRO_BASE_PI and MICRO_BASE_PA LWC and IWC output for March 13, 2000, are shown in Figures 2a,b and 3a,b, respectively.

2. **Active Remote Sensing of Cloud Layers Statistics (ARSCL_STAT).** This VAP combines data from active remote sensors to produce an objective determination of cloud location, radar reflectivity, vertical velocity, and Doppler spectral width. Information about the liquid water path (LWP) in these clouds and the frequency of precipitation is available from the MWR and the Surface Meteorological instruments (SMET, SMOS, or PWS). Frequency distributions are computed and written in an output file in a manner that facilitates user flexibility. The structure enables users to quickly compute statistics for multiples of the half-hour and daily analysis periods that are the

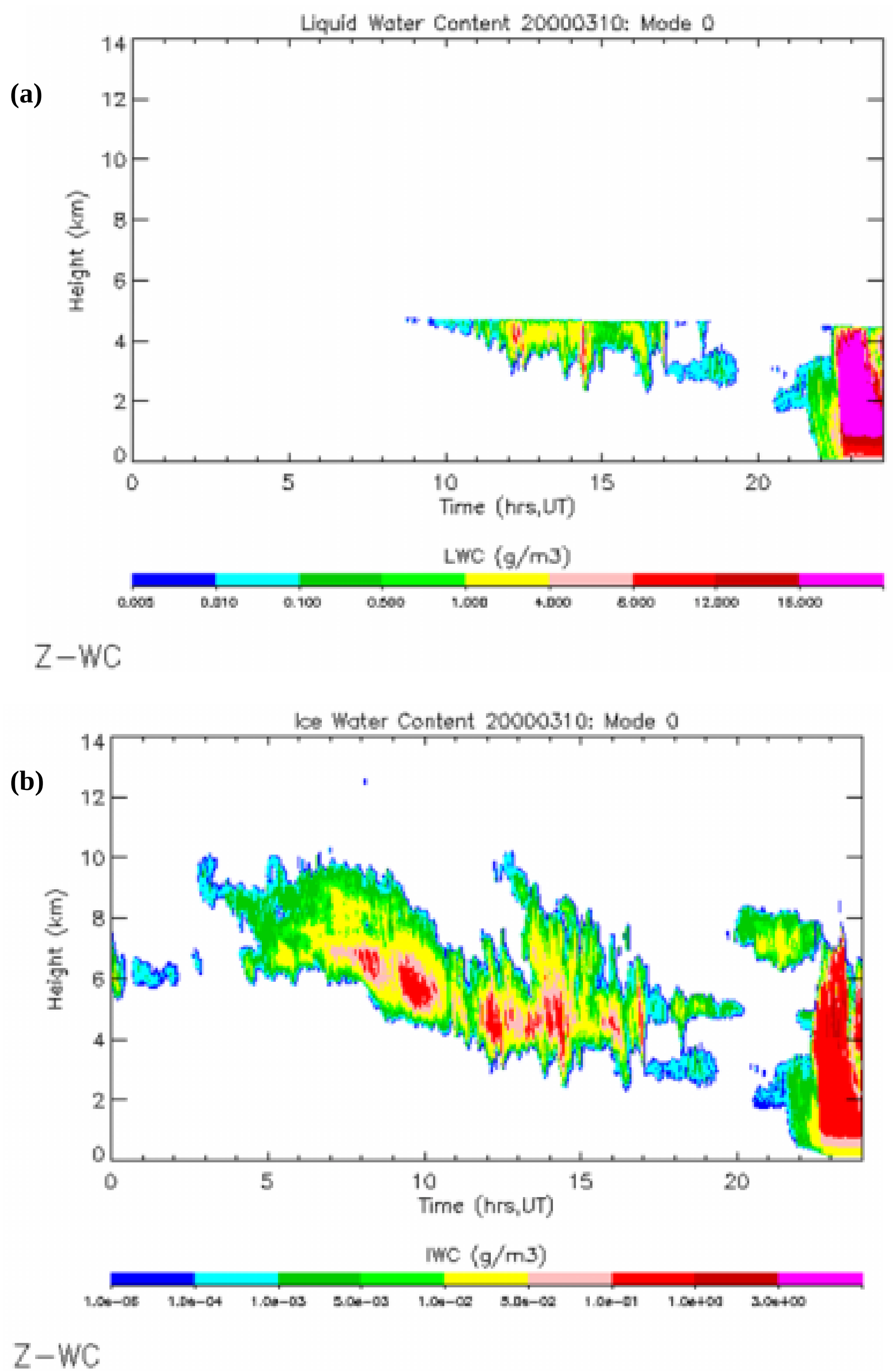

Figure 2. (a) A time versus height cross section of the LWC as a function of height from the MICRO_BASE_PI product on March 10, 2000. (b) A time versus height cross section of the IWC as a function of height from the MICRO_BASE_PI product on March 10, 2000.

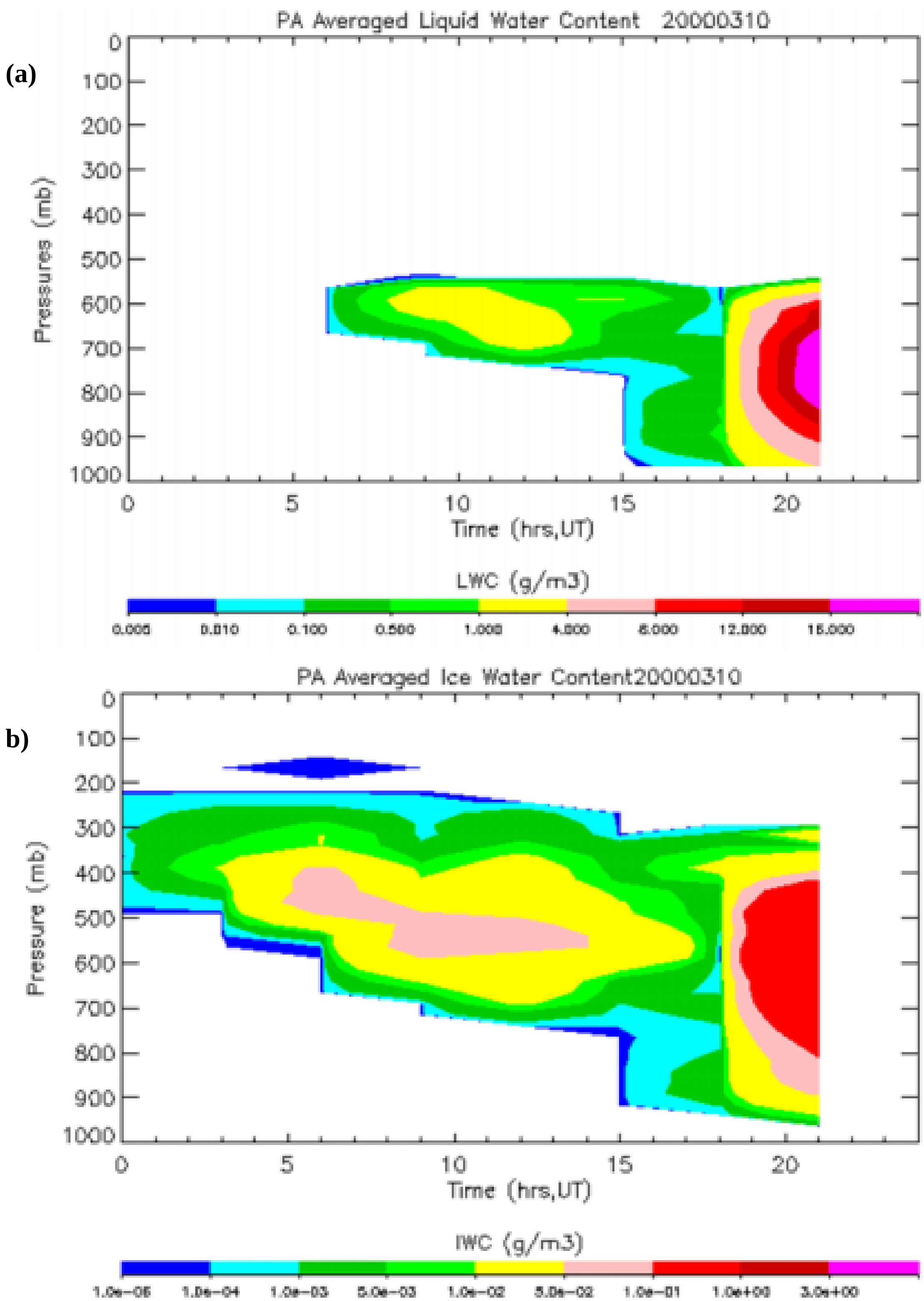

Figure 3. (a) A time versus pressure cross section of the LWC as a function of height from the MICRO_BASE_PI product on March 10, 2000. (b) A time versus pressure cross section of the IWC as a function of height from the MICRO_BASE_PI product on March 10, 2000.

baseline for the statistical computations. Output for 6-hour and daily periods is also provided in graphical format, which allows quick, cursory analysis of the statistical characteristics of the cloud data. A complete description of the ARSCL_STAT VAP is included in this volume (Shi and Miller 2003).

3. **Adiabatic Liquid Water Content (ADIABATIC_LWC).** This VAP computes the adiabatic liquid water content of clouds as a function of height. The cloud base temperature is determined from interpolated soundings (eventually MERGED_SOUNDING will be used for this purpose).

The status of each of the VAPs, discussed above, is shown in Table 1.

Table 1. Status of VAPs on July 10, 2003.

VAP	Status	Comments
ARSCL	Operational	-All sites through 2002 -NSA[a] and Manus into 2003
MERGED_SOUNDING	Development	-Completion: 10/03
MWR STATISTICAL	Development	-IRF/CPWG
MICRO_BASE	Beta Testing	-2000 Cloud IOP Complete -Base_PI; Base_PA
ARSCL_STAT	Beta Testing	-Completion: 10/03
ADIABATIC_LWC	Beta Testing	-Completion: 10/03

(a) North Slope of Alaska

Cloud VAP Interdependencies

A schematic diagram of the interconnections between the cloud VAPs is shown in Figure 4. The core VAPs are enclosed in the dark green box and their relationship to the derivative VAPs shown by the arrows. The circular arrow that connects the MWR_STATISTICAL and MERGED SOUNDING VAPs indicates an interative procedure, which is illustrated in Figure 5. The reason for the iterative procedure is that the MWR_STATISTICAL VAP uses the current sounding to constrain the monthly absorption coefficients, as discussed above, but the output of the MWR_STATISTICAL VAP is used to scale the water vapor content of the sounding. Hence, output from an initial run of MWR_STATISTICAL is used to scale the radiosonde data that are used as the initial input to MERGED_SOUNDING. These scaled radiosonde data are interpolated and further constrained by additional data sources to produce a better estimate of the thermodynamic profile. This improved thermodynamic profile is used in a second run of MWR_STATISTICAL and the output used to rescale the radiosonde data that acts as input to MERGED_SOUNDING.

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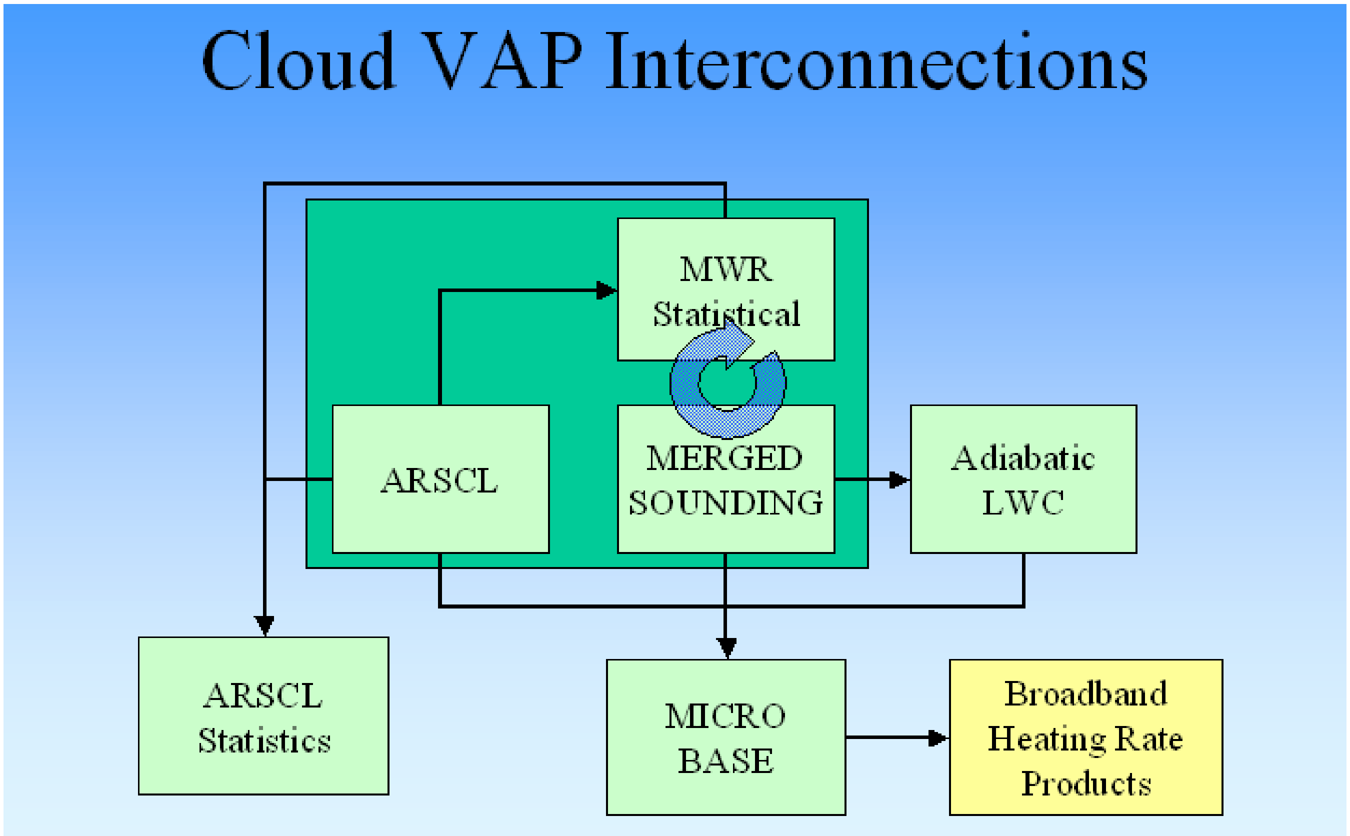

Figure 4. A schematic diagram of cloud VAP interdependencies. Core VAPs are shown enclosed in the darker green box and derivative VAP dependencies are shown with arrows. The circular arrow indicates an iterative procedure.

References

Ivanova, D., D. L. Mitchell, W. P. Arnott, and M. Poellot, 2001: A GCM parameterization for bimodal size spectra and ice mass removal rates in mid-latitude cirrus clouds. *Atmospheric Research*, **59-60**, 89-113.

Liao, L., and K. Sassen, 1994: Investigation of relationships between Ka-band radar reflectivity and ice and liquid water contents. *Atmos. Res*., **34**, 231-248.

Liu, C. L., and A. J. Illingsworth, 1999: Toward more accurate retrievals of ice water content from radar measurements of clouds. *J. Appl. Meteor*., **39**, 1130-1146.

Mlawer, E. J., J. S. Delamere, S. A. Clough, M. A. Miller, and coauthors, 2003: Recent developments on the broadband heating rate profile (BBHRP) value-added product. This proceedings.

Shi, Y., and M.A. Miller, 2003: ARSCL Cloud Statistics-a value-added product. This proceedings.

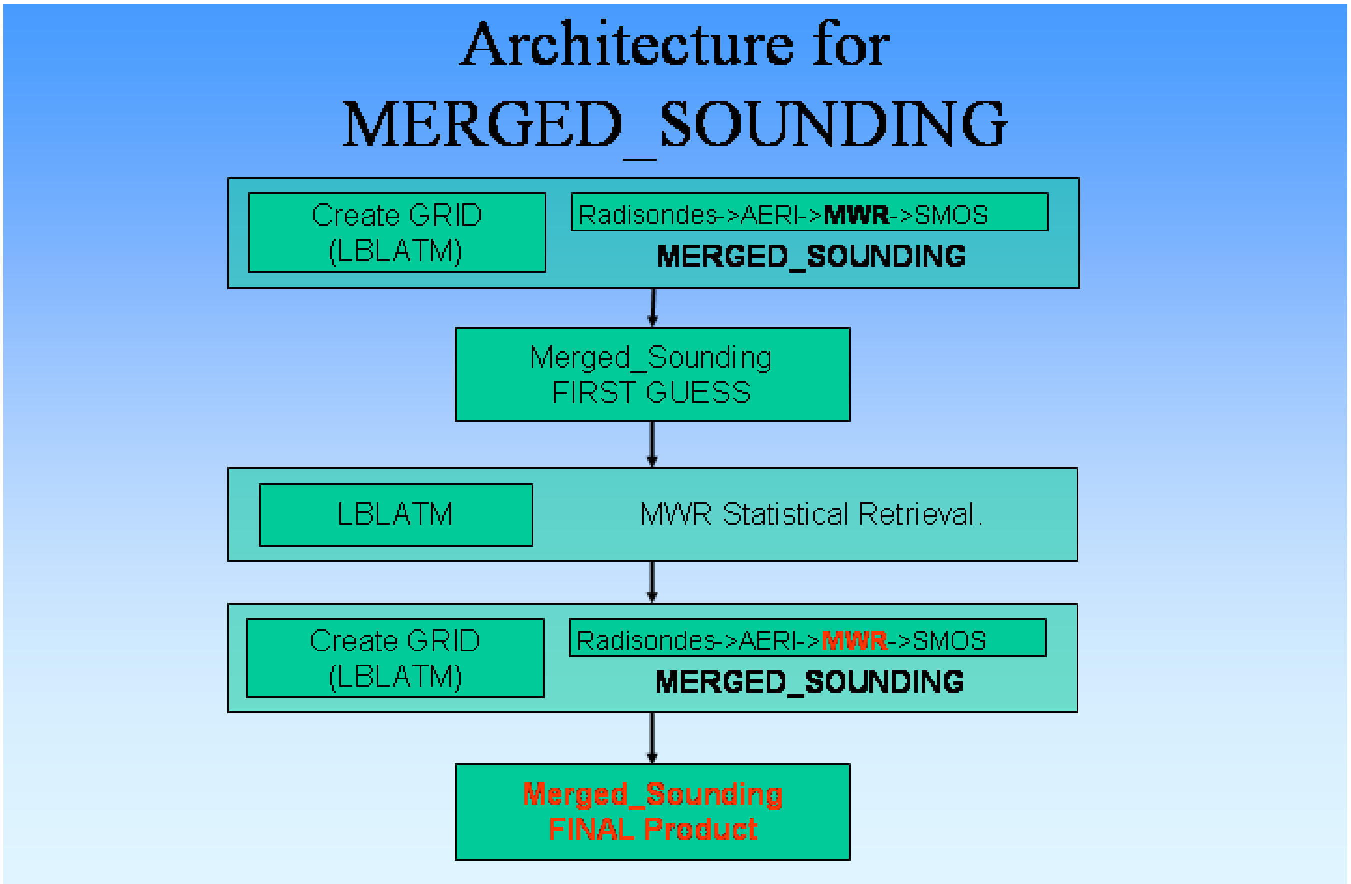

Figure 5. The iterative architecture of the MERGED_SOUNDING VAP.