U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-TR-095

Continuous Baseline Microphysical Retrieval (MICROBASE) Value-Added Product Report

M Wang
A Zhou
M Jensen
K Johnson
SE Giangrande

November 2025

ARM

DOE/SC-ARM-TR-095

Continuous Baseline Microphysical Retrieval (MICROBASE) Value-Added Product Report

Developers: M Wang, A Zhou
Translator: SE Giangrande
Science Sponsors: K Johnson, M Jensen
All at Brookhaven National Laboratory

November 2025

How to cite this document:

Wang, M, K Johnson, A Zhou, SE Giangrande, and M Jensen. Continuous Baseline Microphysical Retrieval (MICROBASE) Value-Added Product Report. U.S. Department of Energy, Atmospheric Radiation Measurement User Facility, Richland, Washington. DOE/SC-ARM-TR-095.

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ADI	ARM Data Integrator
AMF	ARM Mobile Facility
ANX	Andenes, Norway site code
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remote Sensing of Clouds Value-Added Product
ASI	Ascension Island site code
BBHRP	Broadband Heating Rate Profiles Value-Added Product
CBBE	CloudBaseBestEstimate variable of ARSCL
CEIL	ceilometer
ECMWF	European Centre for Medium-Range Weather Forecasts
ENA	Eastern North Atlantic site code
GAN	Gan Island, Maldives site code
GOAMAZON	Green Ocean Amazon 2014/15 field campaign
GUC	Gunnison, Colorado site code
HOU	Houston, Texas site code
IceRE	ice cloud particle effective radius
INTERPSONDE	Interpolated Sonde Value-Added Product
IWC	ice water content
KAZR	Ka-band ARM Zenith Radar
LiqRe	liquid cloud particle effective radius
LWC	liquid water content
MAO	Manacapuru, Brazil site code
MC3E	Midlatitude Continental Convective Clouds Experiment
MICROBASE	Continuous Baseline Microphysical Retrieval Value-Added Product
MMCR	millimeter wavelength cloud radar
MPL	micropulse lidar
MPLCMASK	Cloud Mask from Micropulse Lidar Value-Added Product
MWR	microwave radiometer
MWRRET	Microwave Radiometer Retrievals Value-Added Product
NetCDF	Network Common Data Form
NSA	North Slope of Alaska site code
PVC	Cape Cod, Massachusetts site code
PWV	precipitable water vapor
QC	quality control
RIPBE	Radiatively Important Properties Best Estimate Value-Added Product

SGP	Southern Great Plains site code
TWP	Tropical Western Pacific site code
VAP	value-added product
WACR	W-band ARM Cloud Radar

Contents

Figures

Tables

1.0 Introduction

This technical report describes the Continuous Baseline Microphysical Retrieval (MICROBASE) Value-Added Product (VAP) produced operationally by the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) User Facility. MICROBASE provides a continuous estimate of cloud microphysical properties at ARM fixed observatories and ARM Mobile Facility (AMF) sites. It is designed to run operationally and provide data to the ARM Data Center for scientific distribution. This technical report presents an overview of the VAP as a resource for data users and ongoing records for major updates to these products.

1.1 Background

Clouds play a critical role in the Earth's energy budget through direct interactions with electromagnetic radiation and as a component of the hydrological cycle. Through these interactions clouds provide important feedback to Earth's radiative balance and global circulation, which we must be able to define to accurately predict atmospheric states. Clouds may transmit, reflect, or absorb radiant energy impinging upon them. For a given cloud, the effects of these processes depend on both cloud macrophysical (cloud height, cloud fraction, cloud thickness) and microphysical (water phase, size, and number density of cloud droplets) properties. Therefore, to perform accurate calculations of electromagnetic radiation transfer through the atmosphere and to quantify the role clouds play in the Earth's energy balance and evolving weather patterns, vertical profiles of liquid and ice water contents, and the number and sizes of the cloud particles that contribute to this total water, are required.

1.2 General Product Description

The MICROBASE VAP was developed at Brookhaven National Laboratory in 2002 (Miller and Johnson 2002). The primary purpose for producing this VAP was, and continues to be, to provide the required microphysical values for input to the Broadband Heating Rate Profiles (BBHRP) and Radiatively Important Properties Best Estimate (RIPBE) VAPs to generate estimates of atmospheric radiative heating rates. MICROBASE produces cloud microphysical properties based on the cloud radar measurements taken at ARM sites. To accomplish this, combinations of accepted algorithms are employed. The algorithms interpret radar reflectivity profiles, and microwave brightness temperatures, in the context of the underlying cloud microphysical structure. Many of the algorithms are empirical in nature and assumptions must be made to convert information gathered from the remote and passive sensors into geophysically meaningful quantities. Reasonable assumptions for location, particle distribution, and cloud type have been developed to produce a continuous time series of the microphysical profiles. The product of this analysis, originally called MICROBASEPI, provides instantaneous vertical profiles of liquid water content (LWC), ice water content (IWC), liquid cloud particle effective radius (LiqRe), and ice cloud particle effective radius (IceRe). The output is produced in the same time-height grid as the Active Remote Sensing of Clouds (ARSCL) Value-Added Product as an input, currently with grid spacings at 4-second time intervals and 30-meter height intervals.

1.3 Product History

The product was originally called MICROBASEPI, and it used radar reflectivity collected from ARM's 35-GHz millimeter cloud radar (MMCR). An updated version called MICROBASEKA was later developed after the MMCR was replaced by the Ka-Band ARM Zenith Radar (KAZR). A perturbation method (Zhao et al. 2013) was added later to estimate uncertainties of the cloud microphysical properties in MICROBASEKA, resulting in the upgrade to MICROBASEKAPLUS. A similar product was developed to incorporate the 95-GHz W-Band ARM Cloud Radar (WACR) data sets as input, named MICROBASEW, as is useful for some ARM mobile sites without the KAZR.

Over its extensive 20-year-plus history, the MICROBASE product series has grown, resulting in the use of various ground-based instruments and different product names across different sites. As a result, there is now a need to unify the VAP and these offshoot products, offering a user friendly, all-inclusive solution equipped with the latest algorithms. Moving forward, the product will be named uniformly as MICROBASE, irrespective of radar frequency. Existing MICROBASEKA and MICROBASEKAPLUS data are planned to be reprocessed in 2026 to reflect this naming standardization.

2.0 Input Data

2.1 Required Instruments

The MICROBASE product uses a combination of observations from the following meteorological instruments: the 35-GHz KAZR or 95-GHz WACR, the ceilometer, the micropulse lidar (MPL), the microwave radiometer (MWR) and balloon-borne radiosonde soundings. The instruments reside at ARM sites in close proximity to each other. The data collected by these instruments is first processed into more useable VAPs. As a consequence, the MICROBASE VAP depends solely upon other VAPs for input information, so its availability is often contingent on the availability of those other VAPs/instrument streams for a given ARM observatory or mobile deployment.

2.2 Input Products

The information required by MICROBASE is contained within three ARM VAPs: ARSCL, Microwave Radiometer Retrievals (MWRRET) and Interpolated Sonde (INTERPSONDE). All three input VAPs are routinely produced on a daily schedule or shortly (weeks to months) after collection during a mobile deployment. MICROBASE inputs the daily file of each VAP, selects the vital input variables and then re-grids the data to conform to the ARSCL timescale and height grid. Microphysical quantities are calculated on this time-height grid. The MICROBASE retrieval will not calculate microphysical quantities at any time step that either the ARSCL or INTERPSONDE data are missing, and will not calculate liquid variables if the MWRRET data are missing.

2.2.1 ARSCL

The Active Remote Sensing of Clouds (ARSCL) VAP (Clothiaux et al. 2000) provides a time series of vertical distributions of hydrometeors by combining measurements from the millimeter cloud radar, laser ceilometer, microwave radiometer, and micropulse lidar. Vertical cloud boundaries (i.e., cloud top, cloud base) are determined in ARSCL by assessing KAZR/WACR, lidar and ceilometer data. MICROBASE uses ARSCL cloud boundary information, but ARSCL's best-estimate radar reflectivity factor is the primary data field used by MICROBASE.

2.2.2 MWRRET

The Microwave Radiometer Retrievals (MWRRET) VAP (Turner et al. 2007) uses a physical retrieval algorithm to derive cloud liquid water path (LWP) and column precipitable water from the microwave radiometer measurements. The MWRRET values of vertical column LWP are primarily used to scale reflectivity-based calculations of LWC in MICROBASE. Some data quality flags generated within this VAP are used and transferred to the MICROBASE output product.

2.2.3 INTERPSONDE

The Interpolated Sonde (INTERPSONDE) VAP transforms and linearly interpolates sounding data into continuous daily files on a fixed time-height grid at one-minute time resolution from the surface up to a limit of approximately 40 kilometers. The temperature profile from INTERPSONDE is used (as a first choice) to define the phase of the cloud water and in the parameterization of ice particle effective radius. These choices may also be modified to incorporate phase classification VAPs as available from ARM.

2.3 Table of Input Files

To run this VAP properly, the following daily input files are needed:

Table 1. Input variables – ARSCL.

arsclkazr1kollias.c1(priority 1) **arsclkazr1kollias.c0** (priority 2)	**Long Name**	**Units**
alt	North latitude	degree_N
cloud_base_best_estimate	Cloud base best estimate, based on ceilometer and micropulse lidar	m
height	Height above ground level	m
precip_mean	Precipitation mean from rain gauge	mm/hr
reflectivity_best_estimate	Best-estimate reflectivity	dBZ
reflectivity_clutter_flag	Reflectivity clutter flag	unitless

Table 1 uses the arsclkazr1kollias datastream as an example of radar input datastreams. If the WACR, rather than the KAZR, is the radar of interest at a particular ARM site, the input datastream will be arsclwacr1kollias instead.

Table 2. Input Variables – MWRRET.

mwrret2turn.c1(priority 1) **mwrret1liljclou.c2**(priority 2) **mwrret1liljclou.c1**(priority 3)	**Long Name**	**Units**
stat_lwp / stat2_lwp	Statistically retrieved liquid water path/Cloud liquid water path retrieved using predicted mean radiating temperatures and retrieval coefficients	g/m^2

Table 2 shows input variables used from one of the three possible MWRRET datastreams, depending on their availability from a particular ARM site. A data quality field (qc_stat2_lwp) is also retrieved where available.

Table 3. Input Variables – INTERPSONDE.

interpolatedsonde.c1	**Long Name**	**Units**
height	Height	km
temp	Temperature	degC

3.0 Output Data

MICROBASE output is produced in the same time-height grid as ARSCL. Typically when KAZR is the radar input, the MICROBASE grid is at 4-second time intervals and 30-meter height intervals, for a total of 596 vertical levels. Table 4 lists MICROBASE output fields.

Table 4. Major output variables – MICROBASE.

Name	**Long_Name**	**Units**
base_time	Bas time in Epoch	Seconds since 1970-1- 1 0:00:00 0:00
time_offset	Time offset from base_time	<Set at Runtime>
height	Height above ground level	m
liquid_water_content	Retrieved Liquid Water Concentration	g m-3
liquid_water_cainty_random	Random uncertainty in liquid_water_content	1ontent_uncert
qc_liquid_water_content	Quality check results on variable: Retrieved Liquid Water Concentration	1
ice_water_content	Retrieved Ice Water Concentration	g m-3
ice_water_content_uncertainty_random	Random uncertainty in ice_water_content	1
qc_ice_water_content	Quality check results on variable: Retrieved Ice Water Concentration	1

Name	Long_Name	Units
liquid_effective_radius	Liquid Effective Radius	um
liquid_effective_radius_uncertainty_random	Random uncertainty in liquid_effective_radius	1
qc_liquid_effective_radius	Quality check results on variable: Liquid Effective Radius	1
ice_effective_radius	Ice Effective Radius	um
ice_effective_radius_uncertainty_random	Random uncertainty in ice_effective_radius	1
qc_ice_effective_radius	Quality check results on variable: Ice Effective Radius	1
retrieval_flag	Retrieval flag based on cloud detection status	1
clear_cloud_flag	Clear/Cloudy flag based on variable cloud_base_best_estimate from KAZR ARSCL VAP	1
precip_flag	Precipitation flag based on variable precip_mean from KAZR AR	1
mwr_scale_factor	Ratio of MWR liq to integrated LWC	1
qc_stat2_lwp	Quality check results on variable: input stat2_lwp derived from MWRRET VAP	1
lat	North latitude	degree_N
lon	East longitude	degree_E
alt	Altitude above mean sea level	m

4.0 Algorithm and Methodology

The MICROBASE VAP incorporates the data listed in Section 2. The algorithm is primarily coded in the Python language and uses ARM Data Integrator (ADI) libraries to create NetCDF output files compliant with ARM standards. Contained within the algorithm code are a number of parameterizations, which are applied to the data to retrieve vertical profiles of LWC, IWC, LiqRe, and IceRe.

4.1 Process Flow Diagram

Figure 1 shows the instrument data sets that contribute to MICROBASE, either directly or after additional processing with intermediate VAPs.

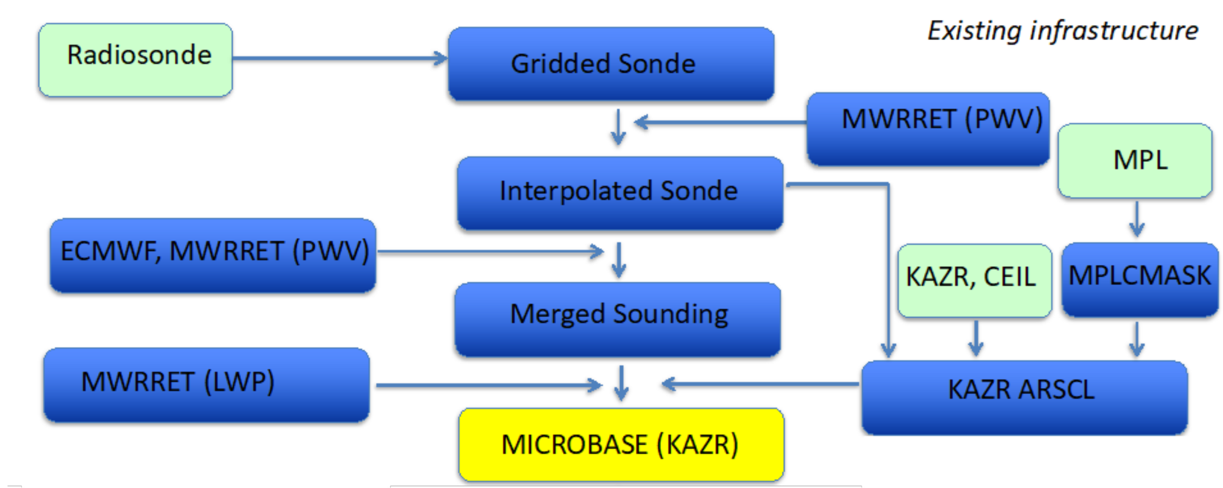

Figure 1. Data flow diagram for the MICROBASE VAP, includes instrument ingest data and upstream VAPs.

Figure 2 shows the primary flow of the main algorithm of the MICROBASE VAP.

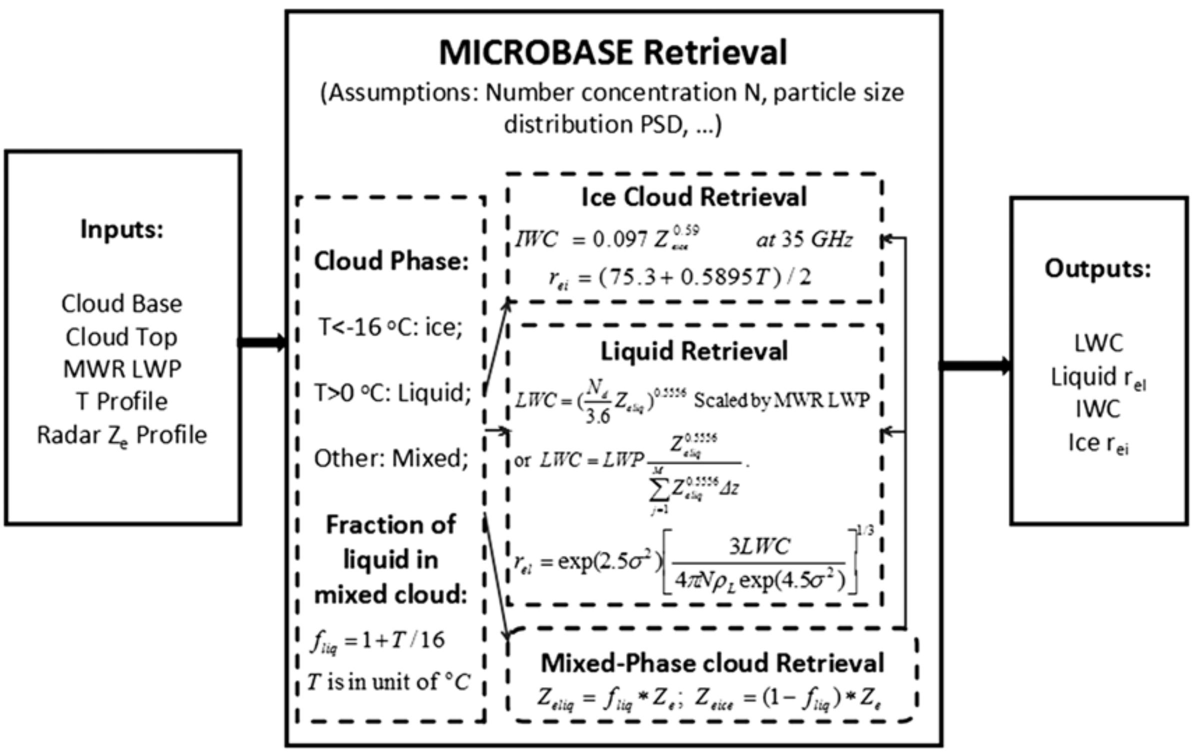

Figure 2. Process flow diagram for the MICROBASE VAP: main algorithms, Zhao et al (2013).

4.2 Algorithm Description

4.2.1 Cloud Water Phase Determination

The MICROBASE algorithm separates the total radar reflectivity into the contribution from liquid water hydrometeors versus that from ice by examining the ambient temperature. If the sonde-measured air temperature is greater than 0ºC, all of the reflectivity measured in a specific time and height bin is considered to be from liquid water. Likewise, if the ambient temperature is less than -16ºC, all of the reflectivity is assumed to be from ice water particles. The reflectivity is partitioned in the following manner, where T is the interpolated sounding temperature in a particular time-height bin and Z_{total} is the total measured radar reflectivity factor in units of (mm^6m^{-3}):

For T <= -16ºC, assume all ice therefore $Z_{ice} = Z_{total}$
For T >= 0ºC, assume all liquid therefore $Z_{liquid} = Z_{total}$

At temperatures between -16 ºC and 0ºC, Z_{total} is partitioned between water and ice using the following mixed-mode fractionating scheme, where Z_{liquid} and Z_{ice} are also in units of (mm^6m^{-3}):

Where -16 < T < 0 C,
ice fraction = - T / 16, and therefore Z_{ice}= ice fraction * Z_{total}
liquid fraction = (1-ice fraction), and therefore Z_{liquid} = liquid fraction*Z_{total}

4.2.2 Determining Ice Water Content and Ice Effective Radius

Once the reflectivity signal is partitioned into the portion from liquid and that from ice cloud hydrometeors, water contents and effective radii can be determined. For ice cloud layers, the water content contained within the ice is determined using the empirical Z-IWC relationship from Liu and Illingworth (2000), where IWC is given in grams per cubic meter:

$$IWC = 0.097 Z_{ice}^{0.59},$$

This relationship is applicable to reflectivity from a 35-GHz radar signal. A number of assumptions about the size, shape, and density of the target ice particles are implicit in the relationship. For example, they are assumed to be unaggregated crystals of the same relative size to density as those found in midlatitude cirrus clouds. Errors are introduced when the assumptions are not met.

The ice cloud particle effective radius (r_{ei}) is determined as a function of temperature. It is based on the empirical relationship of Ivanova et al. (2001):

$$r_{ei} = \frac{(75.3 + 0.5895T)}{2},$$

where T is temperature in degrees Celsius. Here we assume a constant mass-dimension relationship for all hydrometeors as well as a bimodal ice particle size distribution, typical of midlatitude cirrus clouds.

4.2.3 Determining Liquid Water

Determinations of LWC are made based on the radar reflectivity best estimate from the ARSCL VAP. Once the portion of the radar reflectivity derived solely from liquid hydrometeors has been determined, we use the following relationship derived by Liao and Sassen (1994):

$$LWC = \left[\frac{N_0 Z_{liquid}}{3.6} \right]^{1/1.8},$$

where:

N_0 = Reference Cloud particle Number Concentration (cm^{-3})

to produce the initial estimate of LWC at each height bin. Here, N_0 is assumed to be equal to 100 cm^{-3}, as in Liao and Sassen (1994).

The accuracy of the reflectivity-based estimate of LWC is evaluated by comparing it to an independent measurement of cloud liquid water. First, at each 10 second time point, the reflectivity-derived LWC amount is vertically integrated through all cloud layers (cloud base to cloud top) to provide an estimate of liquid water path (LWP). The vertical layers are integrated in height by applying the trapezoid rule to each height bin interval within the clouds as follows:

Integrated LWC = dz/2 (lwc [0] + 2*lwc [1] + 2*lwc [2] + ... +2*lwc [nh-2] + lwc [nh])

where nh is the total number of height bins within all cloud layers. This estimate is compared with the value of LWP measured by the MWR.

4.2.4 Scaling Liquid Water Content to MWR Observations

The algorithm incorporates MWR liquid water path information interpolated to the MICROBASE 4-second time scale, as an additional constraint on total column LWC. If the MWR reports a greater LWP than the integrated radar reflectivity-derived estimate, the latter is scaled to agree. A measure of the degree of scaling is reported as the variable "MWR Scaling Factor," which is calculated as the ratio of the MWR-retrieved LWP to the estimated LWP. A scaled LWC value is then calculated at each height by multiplying LWC by that scaling factor to ensure that the total column LWP matches the LWP retrieved from the MWR. So, at each height:

LWC_{scaled} = LWC * scaleFactor

If the MWR reports a greater amount of cloud liquid water, the MWR constraint is applied to the reflectivity-derived values through the application of the scaling factor. The MWR LWP value is derived from the nearest-in-time positive stat2_lwp value to within a 5-minute window of the MICROBASE profile time. If no stat2_lwp value falls within the 5-minute time period, the scale factor is set to MISSING and LWC_{scaled} is set to MISSING for all heights.

If the reflectivity-derived LWP is greater than zero but the MWR does not see any liquid, the initial phase fractionation procedure (described in Section 4.2.1) is reevaluated. In this case, the radiosonde-derived dry air temperature is examined. If the temperature is < -10°C, the ice_fraction is set to 1.0, all of the reflectivity is deemed to be from ice, and LWC_{scaled} is set to 0. If the temperature is greater than or equal to -10°C, the nearest positive stat2_lwp value is used instead. In the case where no nearby value is found within 5 minutes but the temperature is >= 0, LWC_{scaled} is set to 0. If the temperature is between 0 and -10°C, LWC_{scaled} is set to 0 and the initial calculation of ice fraction is reset to 1.0, thereby allocating all of the reflectivity to ice instead of liquid. If, on the other hand, the MWR sees liquid but the radar does not, the radar reflectivity-derived LWC is neither scaled nor modified.

4.2.5 Determining Liquid Effective Radius

Liquid cloud particle effective radii are computed assuming a log-normal droplet distribution with a width of σ = 0.35 and a mode radius given by the formula:

$$r_{mode} = \left[\frac{3LWC}{4\pi\rho_w N_d \exp\frac{(9\sigma^2)}{2}} \right]^{\frac{1}{3}},$$

where N_d is the cloud particle number concentration, assumed to be 200 cm^{-3}, and ρ_w is the density of water (Frisch et al. 1995). This mode radius is converted to the cloud particle effective radius assuming a log-normal size distribution, such that:

$$r_e = 1.358 r_m$$

4.3 Uncertainties

We calculate the uncertainties of the four main microphysical retrievals by perturbing the inputs and coefficients in the MICROBASE algorithm. The potential error sources for these cloud retrieval algorithms include the retrieval inputs, regression parameters, and assumptions. A set of empirical parameters is adopted in the Cloud Retrievals of MICROBASE in Zhao et al. (2013), and rewritten with variable parameters as follows, and the perturbation variability ranges are determined with in situ data sets as in Table 5. Randomly generated variation of the parameters is added to the original retrieval algorithm. Repeat this process many times, such as one thousand times, to get an average error range. Use relative error to represent the uncertainties.

$$\mathrm{IWC} = aZ_{\mathrm{e}}^{b} \quad (1)$$

$$r_{\mathrm{ei}} = (c + dT)/2 \quad (2)$$

$$\mathrm{LWC} = \mathrm{LWP}\,\frac{Z_{\mathrm{e}}^{g}}{\sum_{j=1}^{M} Z_{\mathrm{e}}^{g}\Delta z} \quad (3)$$

$$r_{\mathrm{el}} = \exp\left(2.5\sigma^{2}\right)\left[\frac{3\mathrm{LWC}}{4\pi\rho_{L}N\exp\left(4.5\sigma^{2}\right)}\right]^{1/3} \quad (4)$$

Table 5. Major output variables – MICROBASE.

Parameters	a	b	c	d	g	σ
	(g/m3)/dBZ	Unitless	µm/°C	µm/°C	Unitless	Unitless
Values	0.097	0.59	75.3	0.5895	0.5556	0.35
Range	0.03–0.22	0.59	75.3	0.23–0.82	0.5–0.6	0.2–0.6

4.3.1 Uncertainties Plots

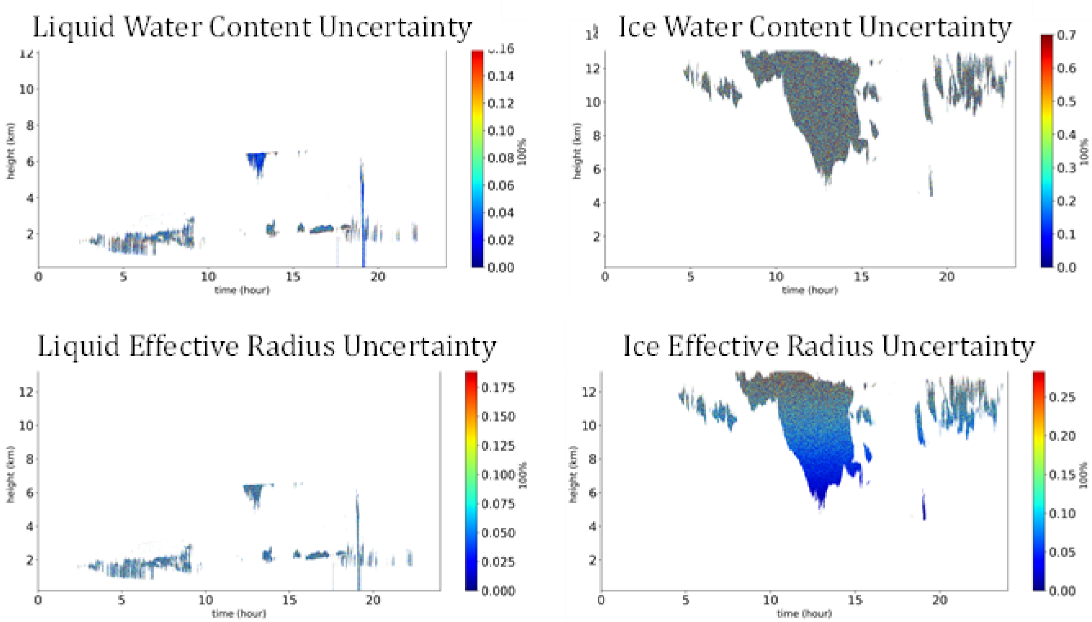

Figure 3. Uncertainties at the ARM's Southern Great Plains (SGP) observatory (Midlatitude Continental Convective Clouds Experiment [MC3E], 2011.06.01).

5.0 Data Quality Assessment

Data quality is assessed using quality control (QC) flags. Some are created de novo (from the beginning) and are unique to this VAP, while others are based on the QC flags of the antecedent VAPs.

5.1 Determining Minimum and Maximum Allowable Values

A combination statistical-technical method is used to determine the minimum and maximum values for the MICROBASE QC flags. These values are then evaluated to determine if they are scientifically reasonable. For example, an effective radius of 0.02µm is not scientifically valid, although it is a possible calculation from the retrieval. The technical portion relies on the known limitations of the instrument. For instance, we cannot detect LWC down to zero gm^{-3}, but we know this to be a reasonable value, so it is included. When deciding on the 2-sigma (95%) or 3-sigma cutoff, a historical search of the literature relevant to a similar instrument and retrieval is appropriate. It is important to note that retrievals based upon empirical algorithms may not be valid outside of the conditions under which they were derived; all calculated quality flags should be used as guides in this respect.

Table 6. Calculated minimum and maximum allowable values.

Product Variable Name	Estimated Minimum Value	Estimated Maximum Value
liquid water content	0.0018 g/m^3 (set to 0.0 g/m^3)	2.5 g/m^3
liquid effective radius	1.46 um	16.0 um
ice water content	1.55e-05 g/m^3 (set to 0.0 g/m^3)	1.0 g/m^3
ice effective radius	14.0 um	38.0 um

Minimum liquid water content is the minimum detectable LWC at any height. Since the instrument sensitivity changes with height, this value is calculated based on the minimum detectable reflectivity for this instrument at the lowest height bin. Minimum detectable reflectivity was determined, specifically for the KAZR measurement. This value may be set to zero.

Maximum LWC is a valid data cutoff, estimated based on the average range of observed LWC values at ARM's SGP observatory. LWC maximum value is based on the selection of a maximum valid effective radius of 16 microns. Using a simple volume calculation and assuming a single size distribution and a droplet radius of 16 microns, we estimate maximum LWC at 2.5 g/m^3. Larger values, up to 25 g/m^3, are measured, but usually attributed to drizzle.

Minimum LiqRe is estimated using the parameterizations of Liao and Sassen (1994) and Frisch et al. (1995) based on a calculated minimum LWC of 0.0018 g/m^3.

Maximum LiqRe is estimated from a roughly 95% point or two standard deviations from the mean of the effective radius distribution of SGP data. A mean value of 4 microns is determined. A maximum radius of 16.27 µm is appropriate if 2.5 g/m^3 is the maximum attainable LWC value, according to Liao and Sassen (1994) and Frisch et al. (1995).

Minimum IWC is estimated based on the minimum detectable reflectivity at the lowest height. A single value is given as an estimate of the minimal detectable IWC at all heights, although this actually varies as a function of height. This value may be set to zero.

Maximum IWC is determined from a statistical analysis of multi-year SGP data, which reveals a maximum value of about 1 g/m^3.

Minimum IceRe is calculated based on the lowest temperature measured of -80°C. Ice Radius is strictly temperature-based as per Ivanova (2001).

Maximum IceRe is calculated from the maximum MICROBASE-assumed temperature for ice. MICROBASE reflectivity-based ice fractionation assumes any reflectivity derived from a bin where the temperature is greater than 0°C is not ice. Statistical analysis at SGP reveals a maximum ice radius of about 37.65 microns. A vast range of physical values for maximum cloud ice particle sizes exists in the literature.

A summary of calculated minimum and maximum allowable values are shown in Table 6.

5.2 Quality Control Flag Descriptions

5.2.1 retrieval_flag

This flag provides information, at every time and height bin, on the performance of the retrieval algorithm. When no cloud is detected, the value of retrieval_flag is set to "0: No cloud detected." When both the radar and MWR see cloud, the value is set to "1: Significant, problem-free data." Occasionally the ARSCL qc_ReflectivityClutterFlag will identify reflectivity that may be derived from signal scatters other than cloud hydrometeors. In this case, the value is set to "2: Cloud and possible clutter contribution." A value of "3: MWR not available for LWC scaling" is given if the MWR data is missing or unavailable but the radar detects a cloud or possible clutter. When the radar return signal does not exist, either due to a malfunction or a location out of the instrument range, the flag value is set to "10: No Reflectivity Data Available."

5.2.2 clear_cloud_flag

Cloud presence is determined by assessing the information collected by the lidar and ceilometer. The information is contained in the CloudBaseBestEstimate (CBBE) variable of the ARSCL VAP data. If both the micropulse lidar and the ceilometer detect a cloud, the ARSCL CBBE flag is set to a value equal to or greater than zero. MICROBASE uses this information to set this clear_cloud_flag to one, indicating that a cloud exists.

5.2.3 qc_stat2_lwp

The MWRRET VAP reports QC information in a bit-packed format for the stat2_lwp variable. Although MICROBASE uses MWRRET data in the retrieval parameterizations only when the integer value of the MWRRET stat2_tliq_flag is less than or equal to one, the integer value of the qc_stat2_lwp flag is also used to flag poor or bad-quality MWRRET data. For this reason a modified version of the MWRRET flag is included within the MICROBASE VAP as the aqc_stat2_lwp flag. The MICROBASE version of this flag is obtained by selecting the MWRRET qc_stat2_lwp QC bit value closest in time to the 4-second interval MICROBASE time.

5.2.4 QC for Primary Data Fields

All QC fields that apply to the primary variables (liquid_water_content, ice_water_content, liquid_effective_radius, ice_effective_radius) have similar bit meanings as in Table 7.

Table 7. qc_stat2_lwp description.

Primary Variable QC Bit	Description	Assessment
bit_1	Radar signal possible out of detection range	Indeterminate
bit_2	Radar signal contains possible clutter	Indeterminate
bit_3	Calculated value out of min/max range	Indeterminate
bit_4	Bad or questionable liquid water path input from MW Radiometer	Indeterminate
bit_5	Liquid precipitation indicated by precip flag	Indeterminate
bit_6	Bad or missing radar signal	Bad

6.0 Example Plots

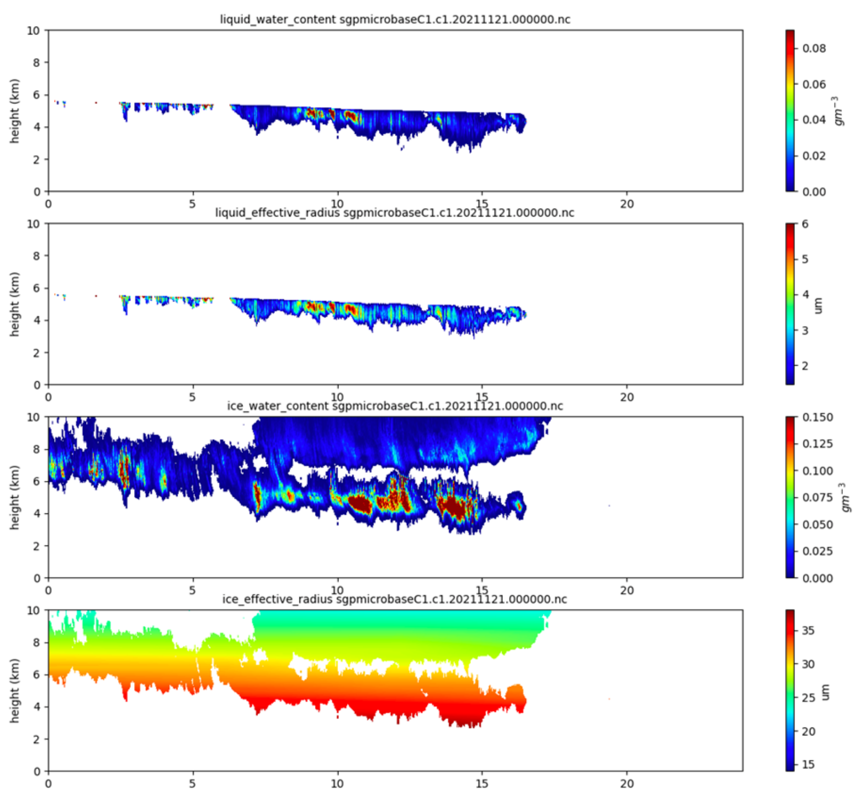

Figure 4. Examples of the quicklook plots produced daily. From top to bottom: liquid water content, liquid effective radius, ice water content, ice effective radius for 2021.11.21 at SGP.

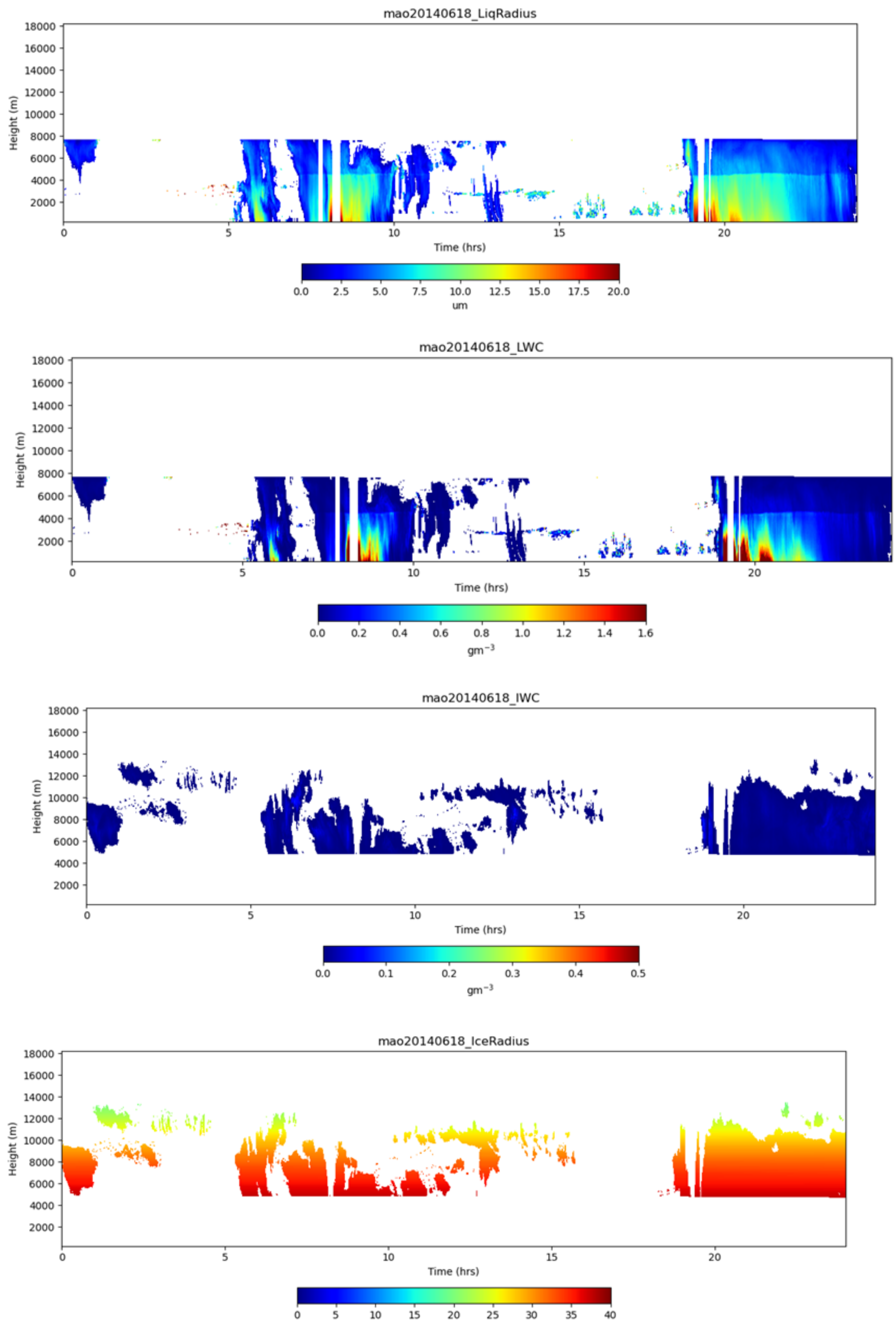

Figure 5. Examples of MICROBASEW quicklook plots. From top to bottom: liquid water content, liquid effective radius, ice water content, ice effective radius for 2014.06.18 at Manacapuru, Amazonas, Brazil; Mobile Facility (GOAMAZON; MAO).

7.0 Sites Where the MICROBASE VAP is Expected to Run

The VAP is primarily intended for sites where ARSCL, MWRRET, and INTERPSONDE VAPs are running. From the existing ARM sites and AMF deployments, these sites would include SGP/C1, Eastern North Atlantic (ENA/C1), Houston, Texas (HOU/M1), Gan Island, Maldives (GAN/M1), Andenes, Norway (ANX/M1), and Ascension Island in the South Atlantic (ASI/M1).

8.0 MICROBASE Legacy Data Availability

The MICROBASE product family has grown during the past 20 years. A summary of data availability is shown in Table 8. For the most up-to-date information, please see the availability time/site charts on the following web page:

https://www.arm.gov/capabilities/science-data-products/vaps/microbase

Table 8. MICROBASE data availability and comparison.

VAP	Site	Availability	Radar	Category	Notes
microbase	GUC	20210914-20230615	KAZR	production	with uncertainties
	NSA	20111111-20140630	KAZR	production	with uncertainties
	SGP	20220101-20250531	KAZR	production	with uncertainties
microbasekaplus	ANX	20191201-20200531	KAZR	evaluation	with uncertainties
	ASI	20160801-20170930	KAZR	evaluation	with uncertainties
	ENA	20150717-20201231	KAZR	evaluation	with uncertainties
	HOU	20211001-20220930	KAZR	evaluation	with uncertainties
	SGP	20110118-20211231	KAZR	evaluation	with uncertainties
microbasew	MAO	20140218-20151130	WACR	evaluation	with uncertainties
	PVC	20121012-20130520	WACR	evaluation	with uncertainties
microbaseka	GAN	20111008-20120208	KAZR	evaluation	no uncertainties
	SGP	20110422-20110606	KAZR	evaluation	no uncertainties
microbasepi2	NSA	20020101-20110322	MMCR	evaluation	with qc flag
	SGP	19961108-20101230	MMCR	evaluation	with qc flag
	TWP	19990701-20110225	MMCR	evaluation	with qc flag
microbasepiavg	NSA	20020101-20110322	MMCR	evaluation	with qc flag
	SGP	19961108-20101230	MMCR	evaluation	with qc flag
	TWP	19990701-20110225	MMCR	evaluation	with qc flag
microbasepi	NSA	20090101-20110322	MMCR	evaluation	no qc flag

VAP	Site	Availability	Radar	Category	Notes
	SGP	20100101-20101230	MMCR	evaluation	no qc flag
	TWP	20050301-20110225	MMCR	evaluation	no qc flag

All the data can be accessed at https://adc.arm.gov/discovery/#/results/s::microbase.

Future MICROBASE products will be named as microbase.c1 or microbase.c0 regardless of the input cloud radar type.

9.0 Summary

MICROBASE provides a continuous baseline of cloud microphysical quantities. It is a mature product that has been evaluated extensively. Although there have been changes to this product through the years, the fundamental algorithm has remained consistent.

10.0 References

Clothiaux, EE, TP Ackerman, GG Mace, KP Moran, RT Marchand, MA Miller, and BE Martner. 2000. "Objective determination of cloud heights and radar reflectivities using a combination of active remote sensors at the ARM CART sites." *Journal of Applied Meteorology* 39(5): 645–665, https://doi.org/10.1175/1520-0450(2000)039<0645:ODOCHA>2.0.CO;2

Frisch, AS, CW Fairall, and JB Snider. 1995. "Measurement of stratus cloud and drizzle parameters in ASTEX with a Kα-band Doppler radar and a microwave radiometer." *Journal of Atmospheric Science* 52(16): 2788–2799, https://doi.org/10.1175/1520-0469(1995)052<2788:MOSCAD>2.0.CO;2

Ivanova, D, DL Mitchell, WP 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, https://doi.org/10.1016/S0169-8095(01)00111-9

Liao, L, and K Sassen. 1994. "Investigation of relationships between Ka-band radar reflectivity and ice and liquid water contents." *Atmospheric Research* 34(1-4): 231–248, https://doi.org/10.1016/0169-8095(94)90094-9

Liljegren, JC, EE Clothiaux, GC Mace, S Kato, and X Dong. 2001. "A new retrieval for cloud liquid water path using a ground-based microwave radiometer and measurements of cloud temperature." *Journal of Geophysical Research – Atmospheres* 106(D13): 14485–14500, https://doi.org/10.1029/2000JD900817

Liu, C-L, and AJ Illingworth. 2000. "Toward more accurate retrievals of ice water content from radar measurements of clouds." *Journal of Applied Meteorology* 39(7): 1130–1146, https://doi.org/10.1175/1520-0450(2000)039<1130:TMAROI>2.0.CO;2

Miller, MA, KL Johnson, DT Troyan, EE Clothiaux, EJ Mlawer, and GG Mace. 2003. "ARM value-added cloud products: Description and status." Proceedings of the Thirteenth ARM Science Team Meeting, U.S. Department of Energy. Richland, Washington. http://www.arm.gov/publications/proceedings/conf13/extended_abs/miller-ma.pdf

Turner, DD, SA Clough, JC Liljegren, EE Clothiaux, K Cady-Pereira, and KL Gaustad. 2007. "Retrieving liquid water path and precipitable water vapor from Atmospheric Radiation Measurement (ARM) microwave radiometers." *IEEE Transactions on Geoscience and Remote Sensing* 45(11): 3680–3690, https://doi.org/10.1109/TGRS.2007.903703

Zhao, C, S Xie, X Chen, MP Jensen, and M Dunn. 2014. "Quantifying uncertainties of cloud microphysical property retrievals with a perturbation method." *Journal of Geophysical Research – Atmospheres* 119(9): 5375–5385, https://doi.org/10.1002/2013JD021112

ARM

www.arm.gov

U.S. DEPARTMENT OF ENERGY

Office of Science