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Raman Lidar Profiles Best Estimate Value-Added Product Technical Report

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January 2012

ARM CLIMATE RESEARCH FACILITY

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1.0 Introduction

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility currently operates two Raman lidars. These systems, which are similar in design, are deployed at the Southern Great Plains (SGP) site, near Lamont, Oklahoma, and at the Tropical Western Pacific (TWP) site near Darwin, Australia.

The ARM Raman lidars are semi-autonomous ground-based systems that transmit at a wavelength of 355 nm with 300 mJ, ~5 ns pulses, and a pulse repetition frequency of 30Hz. The detection systems consist of 10 channels for the SGP system and 9 for the TWP system. These include 2 water vapor channels at 408 nm, 2 nitrogen channels at 387nm, 3 elastic channels, and two temperature channels at 354 and 353nm. Additionally the SGP system has one liquid water channel at 403 nm. Both lidars have two fields-of-view (FOV). Three channels (water vapor, nitrogen, and elastic) have a wide FOV of 2 mrad, and the remaining channels have a narrow FOV of 0.3 mrad. Further design details are given by Goldsmith et al. (1998) and Newsom (2009).

Signals from the various detection channels are processed to produce time- and height-resolved estimates of several geophysical quantities, such as water vapor mixing ratio, relative humidity, aerosol scattering ratio, backscatter, optical depth, extinction, and depolarization ratio. Data processing is currently handled by a suite of six value-added product (VAP) processes, as shown in Figure 1. Collectively, these processes are known as the Raman Lidar Profiles VAP (RLPROF). The processing sequence is broken down in terms of low-level, intermediate-level, and high-level processes. The lowest level VAP process, MERGE, performs operations such as deadtime correction and merging of the raw photon counting and analog signals through a process known as “gluing” (Whiteman et al. 2006, Newsom et al. 2009). The intermediate-level VAP processes use the MERGE VAP to compute the various geophysical quantities of primary interest to the science community. Turner et al. (2002) and Newsom (2009) provide further details concerning the implementation of the low- and intermediate-level VAP processes and their output.

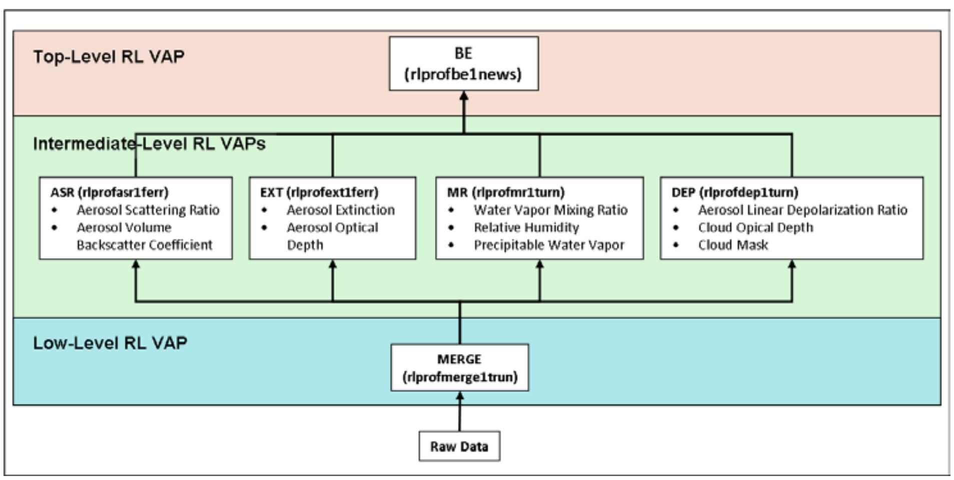

Figure 1. Hierarchy of the RL VAPs. Raw data are first preprocessed by MERGE. The MERGE output is then used by the intermediate-level VAP processes (ASR, EXT, MR, and DEP) to generate time- and height-resolved measurements of water vapor mixing ratio, relative humidity, aerosol scattering ratio, backscatter, optical depth, extinction and depolarization ratio. The top-level VAP process (BE) assembles the primary variables from the intermediate-level VAPs into a single file for use by the end-user.

In addition to the geophysical variables of interest to the science community, the intermediate-level VAPs contain a large amount of engineering, diagnostic, and calibration-related information that is generally not of interest to the end user. The top-level best-estimate (BE) VAP process was introduced in order to bring together the most relevant information from the intermediate-level VAPs. As such, the BE process represents the final stage in data processing for the Raman lidar. Its principal function is to extract the primary variables from each of the intermediate-level VAPs, perform additional quality control, and combine all of this information into a single output file for the end-user. The focus of this document is to describe the processing performed by the BE VAP process.

2.0 Algorithm and Methodology

2.1 Input Data and Interpolation

The BE process reads in primary variables from the ASR, EXT, MR and DEP VAPs, interpolates to a common height grid, and adds quality-control (QC) fields for selected variables. Table 1 provides a detailed listing of all input variable names (and associated datastreams) and the corresponding output variable names.

The BE code, which is written in IDL (Interactive Data Language), is run by specifying the date, site name (e.g., SGP, TWP, etc.), facility designation (e.g. C1, C3, etc.) and temporal resolution in the call to the main routine. The code searches for all intermediate VAPs that match those specifications. If there are no matching ASR, EXT, or MR VAP files, or if all of the data in any of those files are missing, then the BE process aborts. If there are no valid DEP data, the BE code will include the DEP fields as missing values in the final output, as long as there are valid ASR, EXT, and MR data.

Since the temporal resolution is specified in the call to the main routine, all input variables must be defined on the same time grid. As a result, the BE code does no temporal interpolation of the input variables. The height grids, however, can be quite different. All of the intermediate-level VAP processes contain the option to generate output on variable resolution height grids. In general, the height resolution either remains constant or increases with increasing height.

The BE VAP interpolates the variable height resolution input variables to a fixed-height resolution grid. The algorithm currently establishes the height array based on the minimum resolution and maximum height used by the ASR VAP. The height resolution is determined by the difference between the second and first samples in the ASR height array, with a maximum allowable resolution of 150 m.

Input variables are linearly interpolated in the height dimension. When interpolating between two values in which one or more of the values are flagged as missing (i.e. -9999), the resulting interpolated value is also flagged as missing. Also when interpolating outside the bounds of the profile, the interpolated values are flagged as missing.

Both the ASR and DEP VAPs contain estimates of cloud mask. In general, the BE process can be configured to read in either the ASR or the DEP cloud masks. Operationally, however, the default is to read in the DEP cloud mask because this quantity uses both the aerosol scattering ratio and the depolarization ratio to detect the presence of clouds. If the DEP cloud mask data are not available or if all of the values are flagged as missing, then the ASR cloud mask is used.

2.2 QC Fields

The BE VAP process creates quality control (QC) fields for specific output variables. These QC fields are 32-bit integer variables, in which individual bits are set to express certain QC assessments. The dimensions of the QC field match those of the associated variable. Thus, the bit pattern for each sample in the QC field contains information about the data quality of each corresponding sample in the variable array.

QC fields follow the standard naming convention in which the variable name to which the QC applies is preceded by 'qc_'. For example, the QC field associated with the water vapor mixing ratio variable, mr, is qc_mr. The last column in Table 1 lists all QC fields in the BE VAP. Note that not all variables have an associated QC field.

Table 2 lists the QC assessment associated with each significant bit number in the QC field. The assessment describes a data quality condition that users of the data should be aware of. If, for example, the 4th significant bit is set in the QC field, then the value in the corresponding variable is suspected to be contaminated by cloud. If, on the other hand, none of the bits are set in the QC field, then the value in the corresponding variable is deemed to be good.

The BE process performs an extensive number of tests in order to set the appropriate bits in the corresponding QC fields. Table 3 provides a comprehensive listing of all the QC tests that are performed. The first column in Table 3 gives the QC field name, and the third column describes the test that is performed. If the test is true, then the bit number of the QC field listed in column 2 is set.

For all QC fields the first significant bit of the QC field is set if the data are flagged as missing. If the missing value occurs as a result of the of the lidar hatch being closed, then the second significant bit is also set. Samples for which the cloud mask (cmask) is 1 are flagged as cloud contaminated (bit 4 set), except for the depolarization ratio and the cloud mask itself. Additionally, samples above the cloud base height are also flagged as suspect (bit 3 set) because the signals may be strongly attenuated by the cloud. Bit 3 is also set if a particular sample occurs outside expected limits. For variables with associated error estimates, the BE process sets the 5th significant bit if the relative error exceeds 25%.

Finally, it should be stressed that the QC tests performed by the BE process are by no means exhaustive or perfect. It is entirely possible that a value may be deemed good when in fact it is corrupted for one reason or another. Conversely, it is also possible that a value may be deemed bad or suspect when in fact it is good.

Table 1. Primary variable names in the BE VAP and the corresponding input datastream and variable names from the intermediate-level VAPs. Associated QC variable names are also shown.

Input datastream and variable name		Description (units)	Output in rlprofbenews1	
			Variable Name	**QC variable**
Rlprofasr1ferr	cal_asr_1	Aerosol scatter ratio (unitless)	asr	qc_asr
	cal_asr_1_error	Error in cal_asr_1 (unitless)	asr_err	-
	backscatter	Volume backscatter coefficient ($km^{-1}sr^{-1}$)	bscat	qc_bscat
	bscat_err	Error in backscatter ($km^{-1}sr^{-1}$)	bscat_err	-
	cloud_mask	Cloud mask (0=clear,1=cloudy) determined from cal_asr_1	cmask*	qc_cmask
Rlprofext1ferr	extinction_from_ backscatter	Aerosol extinction coefficient (km^{-1})	ext	qc_ext
	extinction_from_ backscatter_error	Error in extinction_from_backscatter (km^{1})	ext_err	-
	aod_bscat	Aerosol optical depth (unitless)	aod	qc_aod
	aod_bscat_error	Error in aod_bscat	aod_err	-
	aod_bscat_max_ht	Maximum height for valid backscatter data from the Raman lidar (km)	aod_max_height	-
	aod_bscat_profile	Cumulative aerosol optical profile (unitless)	aod_profile	qc_aod_profile
Rlprofmr1turn	pwv_mwr	Precipitable water vapor from the MWR (cm)	pwv_mwr	-
	pwv_rl	Precipitable water vapor from the Raman lidar (cm)	pwv	qc_pwv
	pwv_rl_err	Error in pwv_rl (cm)	pwv_err	-
	pwv_rl_fraction	Estimated fraction of the total vertical column sensed by the Raman lidar (unitless)	pwv_fraction	-
	wv_rl_max_height	Maximum height for valid water vapor mixing ratio data from the Raman lidar (km)	mr_max_height	-
	mixing_ratio_3	Water vapor mixing ratio from the Raman lidar ($g\ kg^{1}$)	mr	qc_mr
	mixing_ratio_3_error	Error in mixing_ratio_3 ($g\ kg^{1}$)	mr_err	-
	relative_humidity	Relative humidity from Raman lidar (%)	rh	qc_rh
	temperature	Temperature from radiosonde (C)	temperature	-
	mixing_ratio_sonde	Water vapor mixing ratio from radiosonde ($g\ km^{1}$)	mr_sonde	-
	sample_times_sonde	Radiosonde launch time flag (0=no sonde launch, 1=sonde launch)	sample_times_sonde	-
Rlprofdep1turn	depolarization_ratio	Aerosol Linear Depolarization ratio (%)	dep	qc_dep
	depolarization_ratio_ error	Error in depolarization_ratio (%)	dep_err	-
	cloud_mask	Cloud mask (0=clear,1=cloudy) determined from cal_asr_1 and depolarization_ratio	cmask*	qc_cmask
	cloud_optical_ thickness_aer	Cloud optical thickness computed from elastic channel (unitless)	cot	qc_cot
	cloud_optical_ thickness_aer_error	Error in cloud_optical_thickness_aer (unitless)	cot_err	-

Table 2. QC assessments associated with each bit number in the BE QC fields.

Bit number	QC Assessment
1	Data value not available in input file, data value set to -9999 in output file
2	Hatch closed, data value set to -9999 in output file.
3	Data quality suspect
4	Cloud contaminated
5	Error exceeds 25%

2.3 Quicklooks

The BE process creates a number of quicklook plots. Sample plots of aerosol scattering ratio, aerosol extinction, water vapor mixing ratio, relative humidity, precipitable water vapor, and aerosol optical depth are shown in Figures 2 through 5.

Table 3. Data quality control tests (3^{rd} column) used to set bits for each of the BE QC fields. If the test listed in column 3 is true, then the bit number (column 2) of the corresponding QC field (column 1) is set.

QC Variable Name	Bit number set	Condition
qc_asr	1	asr = -9999 (missing)
	2	asr = -9999 due to hatch closed
	3	0.95 > asr > 10.0 or (asr+ asr_err) < 1.0 or z > cbh
	4	cmask = 1
	5	asr_err/ asr > 0.25
qc_bscat	1	bscat = -9999 (missing)
	2	bscat = -9999 due to hatch closed
	3	0.001 > bscat > 1.0 or (bscat+ bscat_err) < 0.0 or z>cbh or asr = -9999 (missing)
	4	cmask = 1
	5	bscat_err/asr > 0.25
qc_ext	1	ext = -9999 (missing)
	2	ext = -9999 due to hatch closed
	3	-0.02 > ext > 5.0 or bscat = missing or z > cbh
	4	cmask = 1
	5	ext_err/ext > 0.25
qc_aod	1	aod = -9999 (missing)
	2	aod = -9999 due to hatch closed
	3	0 > aod > 10 or 0.0001 > ext.aod > 2.0 or aod_max_height > cbh
	5	aod_err /aod > 0.25
qc_aod_profile	1	aod_profile = -9999 (missing)
	2	aod_profile = -9999 due to hatch closed

	3	z > cbh or 0 > aod_profile > 10
	4	cmask = 1
qc_pwv	1	pwv = -9999 (missing)
	2	pwv = -9999 due to hatch closed
	3	mr_max_height > cbh or 0.0 > pwv > 100 or (pwv + pwv_err) < 0 or pwv_fraction < 0.70
qc_mr	1	mr = -9999 (missing)
	2	mr = -9999 due to hatch closed
	4	cmask = 1
	3	z > cbh or -1.0 > mr > 100 or (mr+mr_err) < 0
	5	mr_err/mr > 0.25
qc_rh	1	rh = -9999 (missing)
	2	rh = -9999 due to hatch closed
	4	cmask = 1
	3	z > cbh or -1.0. > mr.rh > 100 or (mr + mr_err) < 0
	5	mr_err/mr > 0.25
qc_dep	1	rh = -9999 (missing)
	2	rh = -9999 due to hatch closed
	5	dep_err/dep > 0.25
	3	(dep + dep_err) < 0.0
qc_cot	1	rh = -9999 (missing)
	2	rh = -9999 due to hatch closed
	5	cot_err/cot > 0.25
	3	(cot + cot_err) < 0.0

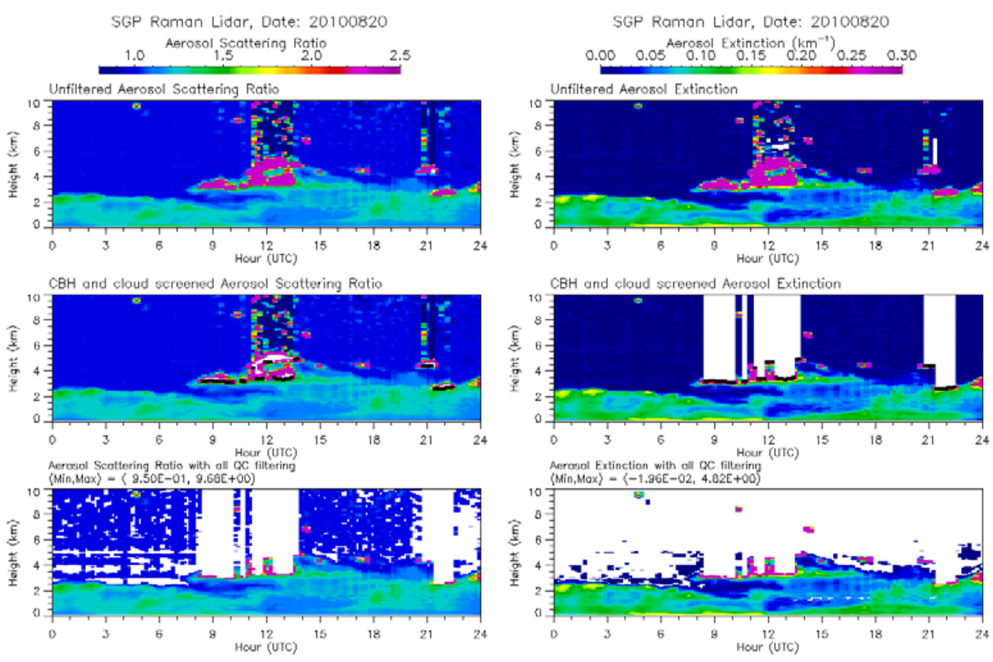

Figure 2. Aerosol scattering ratio (left) and aerosol extinction (right).

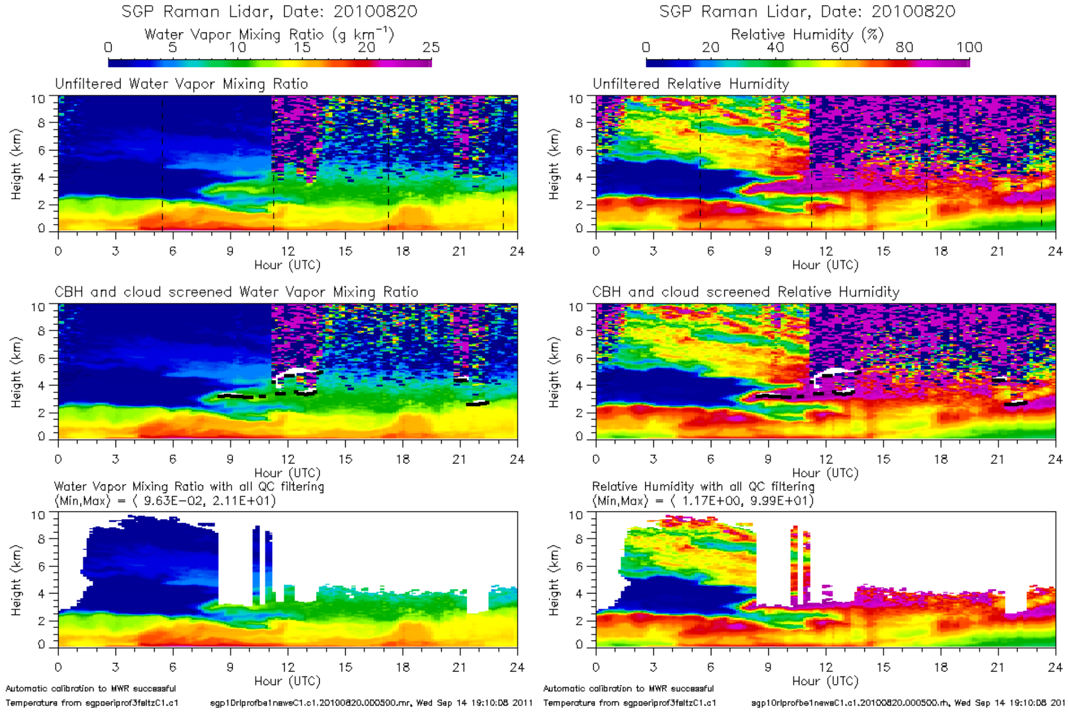

Figure 3. Water vapor mixing ratio (left) and relative humidity (right).

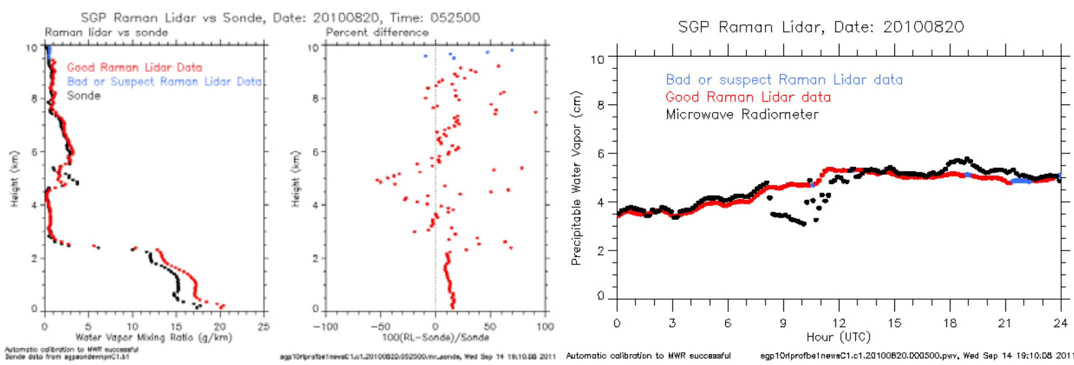

Figure 4. Comparison between the Raman lidar and radiosonde water vapor mixing ratio (left and middle). Comparison between the Raman lidar and Microwave Radiometer precipitable water vapor (right).

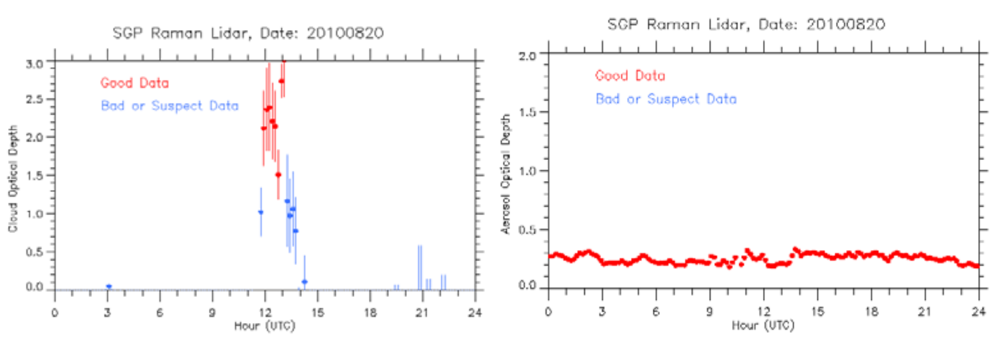

Figure 5. Cloud optical depth (left), and aerosol optical depth (right).

3.0 Summary

This document summarizes the processing used to generate the Raman lidar BE VAP. This includes a description of all input and output variables, the height interpolation scheme, and all quality control tests used in the BE process.

The BE process represents the final stage in data processing for the Raman lidar. Its purpose is to assemble all the primary variables from each of the intermediate-level RL VAPs, perform additional quality control, and combine all of this information into a single output file for the end user. The intent is to provide a single final data product that is free of extraneous information and easier for the end-user to understand and use.

4.0 References

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