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Ka-Band ARM Zenith Radar Corrections (KAZRCOR, KAZRCFRCOR) Value-Added Products

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ARM

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
KAZR	Ka-Band ARM Zenith Radar
KAZR-ARSCL	KAZR Active Remote Sensing of Clouds
KAZRCFRCOR	KA-Band ARM Zenith Radar CF-Radial, Corrected
KAZRCOR	Ka-Band ARM Zenith Radar Corrections
SNR	signal-to-noise ratio
VAP	value-added product

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1.0 Introduction

The Ka-Band Atmospheric Radiation Measurement (ARM) Zenith Radar Corrections (KAZRCOR) and KA-Band ARM Zenith Radar CF-Radial, Corrected (KAZRCFRCOR) value-added products (VAPs) perform several corrections to the ingested KAZR moments and also create a significant detection mask for each radar mode. The VAPs compute gaseous attenuation as a function of time and radial distance from the radar antenna, based on ambient meteorological observations, and correct observed reflectivities for that effect. Mean Doppler velocities are dealiased to correct velocities whose magnitudes exceed the radar's Nyquist velocity. Input KAZR data fields are passed through to the KAZRCOR or KAZRCFRCOR output files, in their native time and range coordinates. Complementary corrected reflectivity and velocity fields are provided, along with a mask of significant detections and a number of data quality flags.

This report covers the KAZRCOR VAP as applied to the original KAZR radars and the upgraded KAZR2 radars. Originally, prior to late 2019, there were two separate code bases for the different radar versions. Following the harmonization of KAZR and KAZR2 data formats in 2019, only a single code base is required. The new combined KAZR and KAZR2 code base is called the KAZRCFRCOR VAP. The 'cfr portion of the VAP name refers to the Radial Climate and Forecasting data format standards that are used in these data sets. Throughout this report, references to 'KAZRCOR' should be taken to apply to the 'KAZRCFRCOR' VAP as well unless there is an explicit statement to the contrary.

2.0 Input Data

Input data for the KAZRCOR VAP consists of ingested KAZR mode data from all available KAZR modes, as well as thermodynamic profiles from the INTERPOLATEDSONDE VAP[1]. The KAZRCOR VAP processes one day of data at a time, producing daily output files.

2.1 KAZR Input

Input KAZR measurements are supplied from individual ingested radar mode files, with datastream names 'kazrge', 'kazrmd', 'kazrhi', and 'kazrpr.' Inputs to the KAZRCFRCOR VAP are supplied by input datastreams 'kazrcfrge', 'kazrcfrmd', 'kazrcfrhi', and 'kazrcfrpr' (or, in the case of sites with KAZR2 radars, which are the next-generation KAZRs, the 'kazrcfr' in the datastream name is replaced with 'kazr2cfr.'). The possible data modes are:

GE: 'general' short-pulse burst mode, available at all radar ranges
MD: 'moderate sensitivity', longer chirp mode, not available at lowest radar ranges
HI: 'highest sensitivity' longest chirp mode, not available at lowest radar ranges (this mode is rarely used)
PR: 'precipitation' short-pulse burst mode, attenuated to avoid saturation in precipitation.

The VAP can be run with either reflectivity-calibrated 'b1-level' KAZR data or with the originally ingested uncalibrated, 'a1-level' data, differentiated by the data file name suffix '.b1' or '.a1',

[1] https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-183.pdf

respectively. It is not necessary for all KAZR modes to exist (generally they do not) in order to run the VAP. Table 1 lists input variables that are used and/or modified (due to, e.g., attenuation correction or velocity dealiasing) within the KAZRCOR VAP. Table 2 is a similar table for the KAZRCFRCOR VAP. All other KAZR variables are simply passed through to the output product.

Table 1. KAZRCOR VAP: Major input kazr variables.*

Datastream	KAZRCOR Input Variables	
	KAZR radar	**KAZR2 radar**
kazrge kazrmd kazrhi kazrpr	reflectivity_copol reflectivity_xpol (if exists)	reflectivity
	mean_doppler_velocity_copol mean_doppler_velocity_xpol (if exists)	mean_doppler_velocity
	signal_to_noise_ratio_copol signal_to_noise_ratio_xpol (if exists)	snr_copol snr_xpol

* Most other kazr fields are simply 'passed through' the VAP without being used.

Table 2. KAZRCFRCOR VAP: Major input kazrcfr variables.*

KAZRCFRCOR Input Variables	
KAZR radar Datastreams: kazrcfrge, kazrcrmd, kazrcfrhi, kazrcfrpr	**KAZR2 radar** Datastreams: kazr2cfrge, kazr2crmd, kazr2cfrhi, kazr2cfrpr
reflectivity reflectivity_crosspolar_v	
mean_doppler_velocity mean_doppler_velocity_crosspolar_v	
signal_to_noise_ratio_copolar_h signal_to_noise_ratio_crosspolar_v	

Note that KAZRCOR output data is used as a primary input to the KAZR Active Remote Sensing of Clouds (KAZR-ARSCL) VAP.

2.2 INTERPOLATEDSONDE Input

The INTERPOLATEDSONDE VAP supplies the meteorological measurements, temperature, relative humidity, and pressure, which are used to compute gaseous attenuation. When INTERPOLATEDSONDE is available, the correction is applied. Information on this product is available in its technical report, https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-183.pdf.

Table 3. Input INTERPOLATEDSONDE variables.

Datastream	Input Variable
interpolatedsonde	bar_pres rh_scaled temp

3.0 Algorithm and Methodology

KAZRCOR VAP processing is applied to KAZR mode observations on a mode-by-mode basis, resulting in corrected KAZR moments together with a significant detections mask and several quality control fields. The corrected and additional fields, along with most remaining KAZR fields, are output to create ‘kazr*cor*<mode>’ data files (KAZRCOR VAP), or ‘kazrcfrcor<mode> files (KAZRCFRCOR VAP). Figure 1 shows a high-level flowchart of KAZRCOR processing. The boxes colored orange in the figure represent the more complex pieces of the processing flow. Each of these is discussed in more detail below.

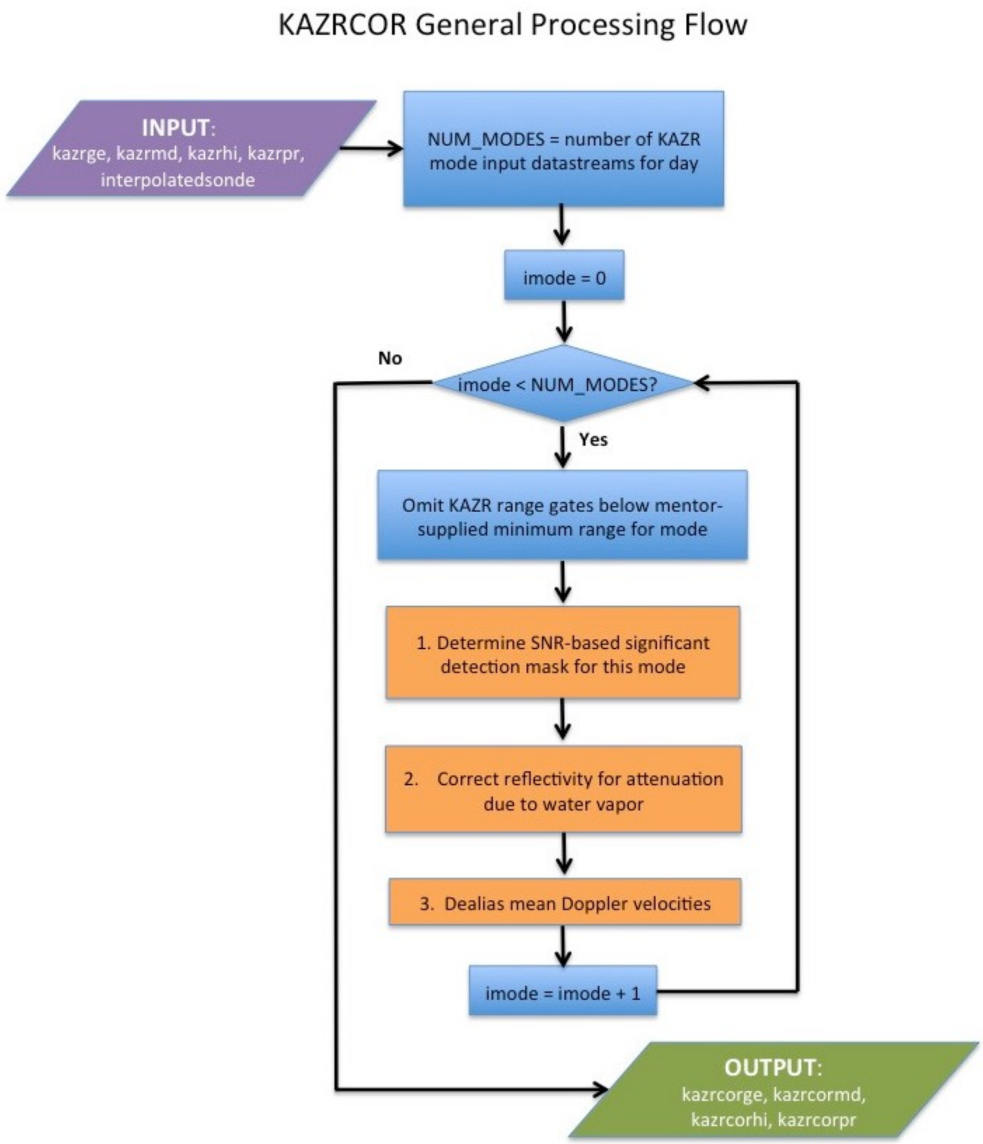

Figure 1. High-level flowchart of the KAZRCOR VAP.

3.1 Significant Detection Mask

The KAZRCOR significant detection mask algorithm (see orange box labeled '1.' in Figure 1, expanded in Figure 2) differentiates significant radar returns from background noise by applying the Hildebrand and Sekhon (1974) technique to the KAZR signal-to-noise-ratio (SNR) field on a time-profile-by-time-profile basis. For each SNR time profile, the value determined to be 'noise,' plus 1.5 standard deviations of the 'noise' values, is taken as the minimum SNR value qualifying as a significant detection. Once significant detections are determined for each time profile, a 5x5 point majority filter is applied to the time-height mask to eliminate isolated significant detections.

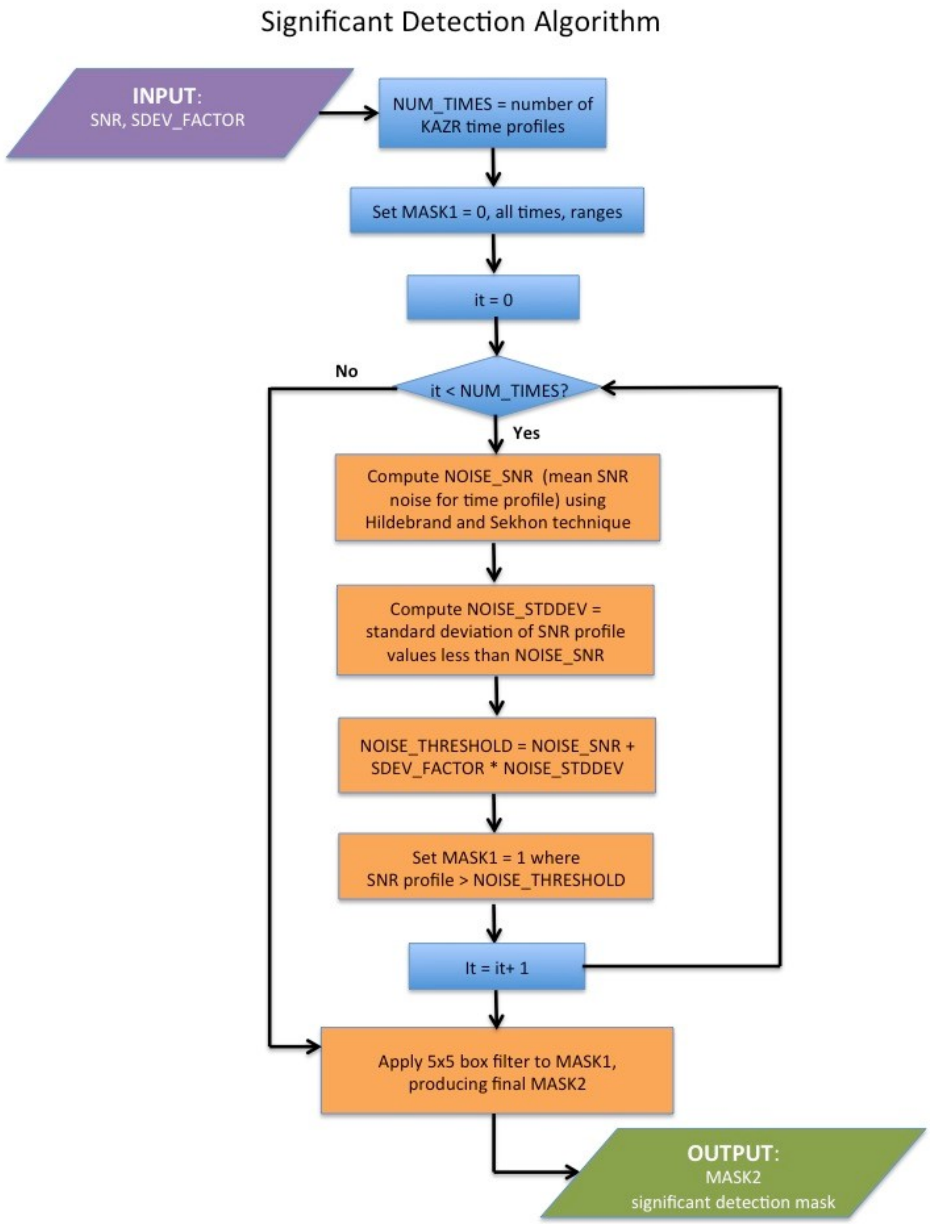

Figure 2. Flowchart of the KAZRCOR significant detection algorithm.

3.2 Gaseous Attenuation

Next, atmospheric signal attenuation due to water vapor and oxygen is computed for each time profile, following Ulaby et al. 1981 (see orange box labeled '2.' in Figure 1). The method uses temperature, atmospheric pressure, and relative humidity from ARM's INTERPOLATEDSONDE product as input. The computed attenuation is then added back to measured reflectivity to create a corrected reflectivity field.

3.3 Velocity Dealiasing

Finally, in the orange box numbered 3 in Figure 1, KAZR mean Doppler velocity is examined to identify and correct regions that are 'folded.' Folded velocities occur when the observed hydrometeor velocities exceed the KAZR Nyquist velocity[2], which is the maximum velocity measurement (in absolute value) that the radar can report. Dealiasing is a two-step process. First, dealiasing is done time-profile-by-time-profile, examining the absolute value of velocity differences over a single range gate (for high-SNR observations only, considered here to be greater than -5 dB) from cloud top downward. This portion of the dealiasing algorithm is depicted in Figure 3. The implicit assumption is that no aliasing exists at cloud top. When the absolute value of the gate-to-gate velocity difference exceeds 1.5 times the Nyquist velocity, a velocity fold is identified at that range. For each folded velocity, twice the Nyquist velocity is subtracted from or added to the folded velocity, depending on whether or not (respectively) the velocity difference is greater than 1.5 times the Nyquist value. Once the highest-in-range folded velocity has been addressed in this manner, the velocity differences from range gate to range gate are recomputed. This procedure is repeated until no folds are found in each time profile.

Next, velocities are dealiased in time, for radar ranges up to 6 km, over successively longer influence times, comparing velocity at each time with 2-minute, 4-minute, and finally 10-minute moving velocity averages, addressing significant velocity jumps similarly to the profile-by-profile technique described above.

[2] Nyquist values can be found in the global attributes.

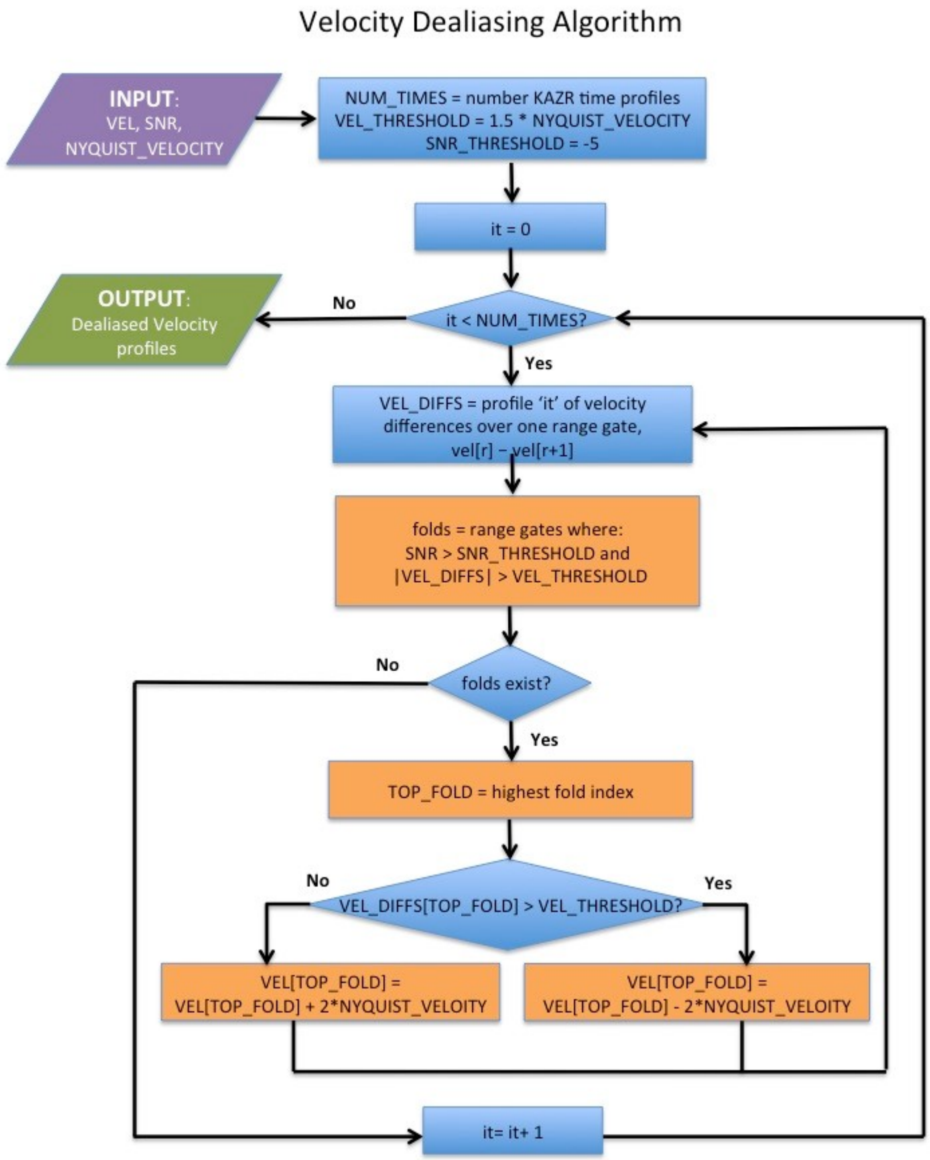

Figure 3. Flowchart of the KAZRCOR profile-by-profile velocity dealiasing algorithm.

3.4 Application of Minimum Usable Range

There exists a minimum valid range, below which the radar data should not be used because the radar is still transmitting signal (hence does not have full power). The KAZRCOR VAP marks as MISSING all data below this radar range.

4.0 Output Data

An output datastream is created for each input KAZR mode datastream. For example, if a given day has two input KAZR datastreams, ‘kazrge.b1’ and ‘kazrmd.b1’, there will be two (and only two) output datastreams created, called ‘kazrcorge.c1’ and ‘kazrcormd.c1’.

4.1 Output Variables

The output KAZRCOR datastreams contain all fields from the corresponding mode’s input KAZR datastream on the original time and range grids. The output reflectivity and mean Doppler velocity field(s) are corrected versions (for gaseous attenuation and aliasing, respectively) of the original input KAZR fields. In addition, the output datastream contains a significant detection mask, gaseous attenuation correction and velocity dealiasing fields, plus quality control fields for the radar moments. Table 3 lists the new fields provided in the KAZRCOR output products, while Table 4 shows similar information for the KAZRCFRCOR VAP.

Table 4. Output KAZRCOR variables (in addition to ‘passed through’ kazr fields).

<table>
<tr><th rowspan="2">Data streams</th><th colspan="2">KAZRCOR Output ‘new’ Variables
(in addition to kazr passed-through fields)</th></tr>
<tr><th>KAZR</th><th>KAZR2</th></tr>
<tr><td rowspan="13">kazrcorge
kazrcormd
kazrcorhi
kazrcorpr</td><td colspan="2">significant_detection_mask</td></tr>
<tr><td>mean_doppler_velocity_copol_dealias_flag
mean_doppler_velocity_xpol_dealias_flag</td><td>mean_doppler_velocity_dealias_flag</td></tr>
<tr><td>gaseous_attenuation_correction_copol
gaseous_attenuation_correction_xpol</td><td>gaseous_attenuation_correction</td></tr>
<tr><td colspan="2">temp</td></tr>
<tr><td colspan="2">rh</td></tr>
<tr><td colspan="2">bar_pres</td></tr>
<tr><td>qc_reflectivity_copol
qc_reflectivity_xpol (if reflectivity_xpol exists)</td><td>qc_reflectivity</td></tr>
<tr><td>qc_mean_doppler_velocity_copol
qc_mean_doppler_velocity_xpol (if xpol exists)</td><td>qc_mean_doppler_velocity</td></tr>
<tr><td>qc_spectral_width_copol
qc_spectral_wdith_xpol (if xpol exists)</td><td>qc_spectral_width</td></tr>
<tr><td>signal_to_noise_ratio_copol
signal_to_noise_ratio_xpol (if xpol exists)</td><td>snr_copol
snr_xpol</td></tr>
<tr><td colspan="2">qc_temp</td></tr>
<tr><td colspan="2">qc_rh</td></tr>
<tr><td colspan="2">qc_bar_pres</td></tr>
</table>

Table 5. Output KAZRCFRCOR variables (in addition to 'passed through' kazrcfr fields).

KAZRCFRCOR Output 'new' Variables (in addition to kazrcfr passed-through fields)	
KAZR Datastreams: kazrcfrcorge, kazrcfrcormd, kazrcfrcorhi, kazrcfrcorpr	**KAZR2** Datastreams: kazr2cfrcorge, kazr2cfrcormd, kazr2cfrcorhi, kazr2cfrcorpr
significant_detection_mask	
mean_doppler_velocity_dealias_flag mean_doppler_velocity_crosspolar_v_dealias_flag	
gaseous_attenuation_correction	
temp	
rh	
bar_pres	
qc_reflectivity	
qc_mean_doppler_velocity qc_mean_doppler_velocity_crosspolar_v	
qc_spectral_width qc_spectral_wdith_crosspolar_v	
qc_gaseous_attenuation_correction	
qc_temp	
qc_rh	
qc_bar_pres	

4.2 Calibrated versus Uncalibrated Output Datastreams

As noted earlier, the KAZRCOR VAP may be run using calibrated KAZR data as input (kazr*.b1 datastreams) or uncalibrated KAZR data (kazr*.a1). When processing calibrated data, KAZRCOR produces kazrcor*.c1 output products, which are archived and used as input in KAZR-ARSCL VAP processing. However, there is also a need for an interim KAZR-ARSCL VAP product, prior to KAZR calibration. To provide input for this processing, an uncalibrated version of the KAZRCOR product, bearing the datastream name, 'kazrcor*.c0,.' is produced using uncalibrated kazr*.a1 datastreams as input. (In the case of the KAZRCFRCOR VAP, 'kazrcfrcor*.c1 products are created for calibrated inputs, and 'kazrcfrcor*.c0' products are created from uncalibrated inputs.)

5.0 Summary

The KAZRCOR VAP applies corrections to two major KAZR moments fields, reflectivity and mean Doppler velocity. A significant detection mask is created, making the radar moments much more useful for most users. In addition, the KAZRCOR VAP serves as input to the widely used KAZR-ARSCL product.

6.0 Example Plots

A sample image of KAZR general mode (kazrge) reflectivity and mean Doppler velocity before (Figure 4) and after (Figure 5) KAZRCOR processing are presented for ARM's Southern Great Plains SGP) site, SGP-C1, on July 30, 2013. Quicklooks similar to Figure 5 are produced as part of routine KAZRCOR processing. In the original KAZR image, Figure 4b, note the red and magenta-colored areas of the Mean Doppler Velocity image below 4 km from approximately 0130-0830Z. These are regions where the KAZR-measured velocities are aliased since the absolute value of the actual hydrometeor velocities exceed the KAZR Nyquist velocity of 5.96 m s-1. After KAZRCOR processing, Figure 5a shows reflectivity corrected for water vapor attenuation. For this date and time the correction is very small, and is difficult to detect in the image. Figure 5b shows mean Doppler velocity, after dealiasing. Note that the red and magenta velocities from Figure 4b have been replaced by shades of blue, indicating consistent downward motion, as expected. Figure 5c shows a mean Doppler velocity flag, indicating in green those time-height points where dealiasing was performed. Finally, Figure 5d shows the significant detections in green as determined for this period.

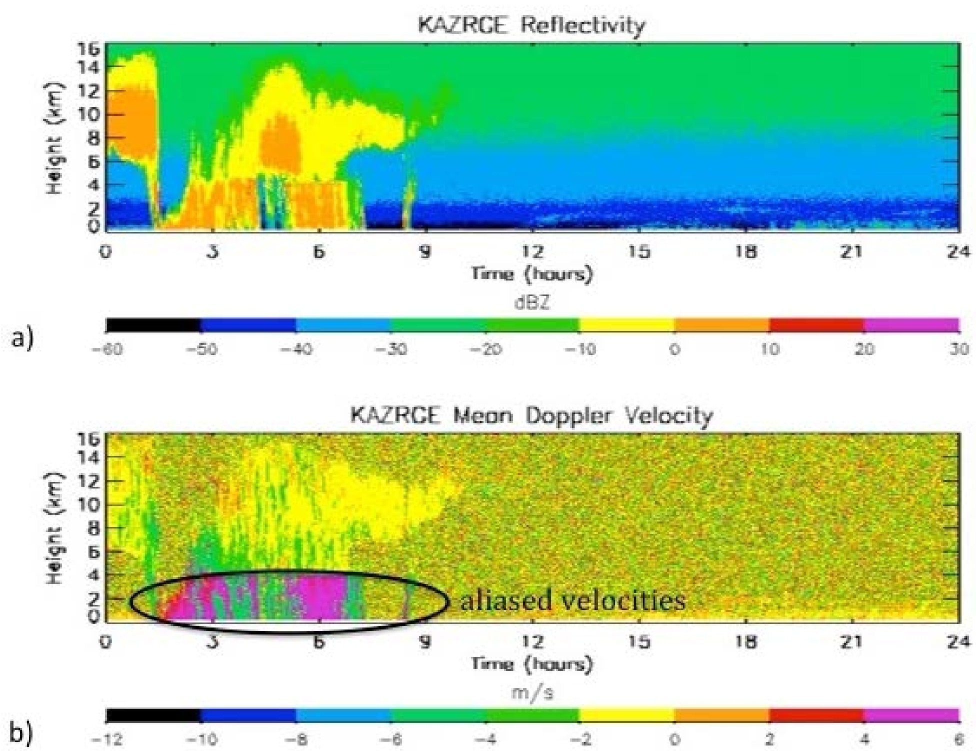

Figure 4. Sample image of KAZR general mode a) reflectivity and b) mean Doppler velocity prior to KAZRCOR processing. Image shows observations from ARM's SGP-C1 site, July 30, 2013.

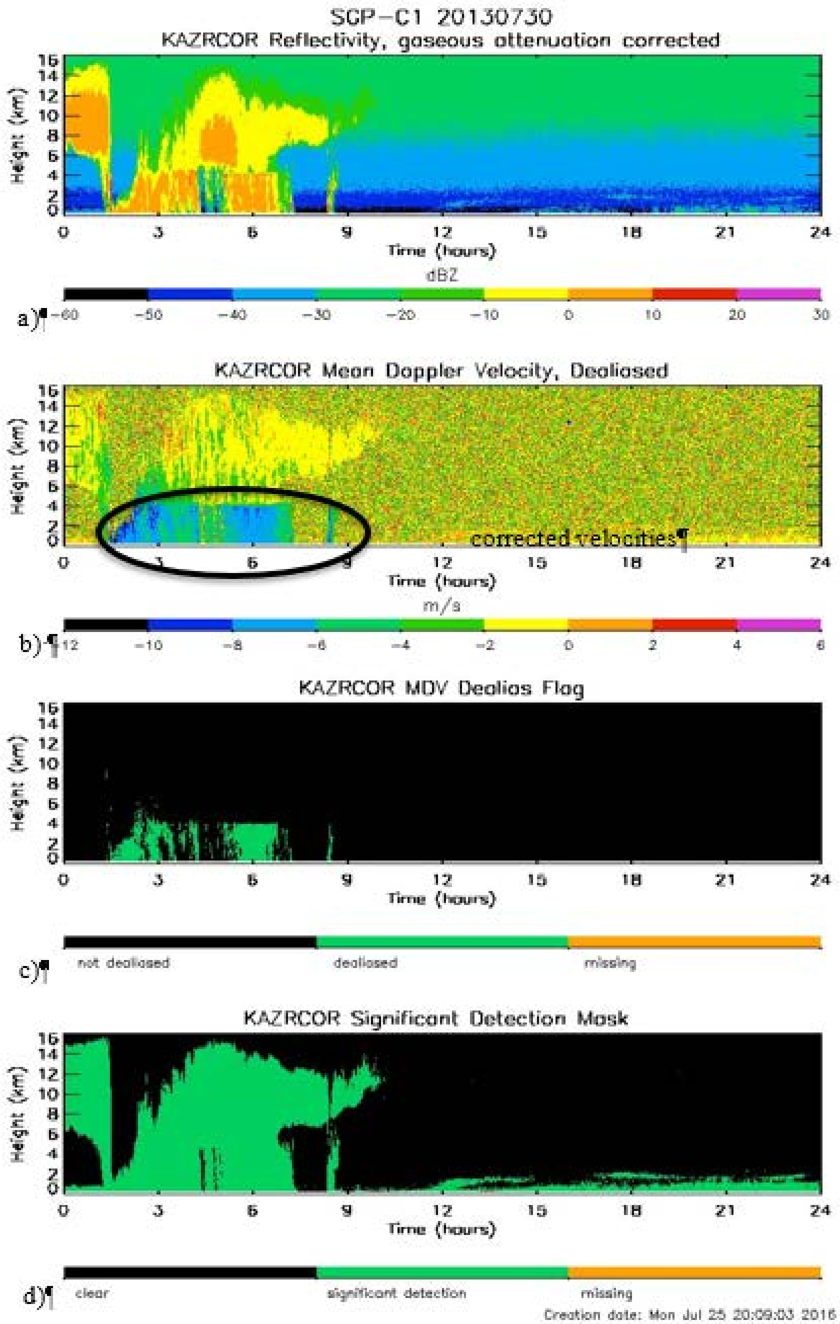

Figure 5. Image created by KAZRCOR VAP for SGP-C1 on July 30, 2013. The images represent KAZR general mode a) reflectivity after gaseous attenuation correction, b) mean Doppler velocity after dealiasing, c) flag indicating areas where dealiasing was done, and d) significant detection mask.

7.0 References

Hildebrand, PH, and RS Sekhon. 1974. "Objective determination of the noise level in Doppler spectra." *Journal of Applied Meteorology* 13(7): 808−811, http://doi.org/10.1175/1520-0450(1974)013<0808:ODOTNL>2.0.CO;2

Ulaby, FT, RK Moore, and AK Fung. 1981. *Microwave Remote Sensing: Active and Passive, Vol. I -- Microwave Remote Sensing Fundamentals and Radiometry*. Addison-Wesley, Advanced Book Program, Reading, Massachusetts.

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