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COMBLE Radar b1 Processing: Corrections, Calibrations, and Processing Report

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February 2023

ARM

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Acronyms and Abbreviations

2D	two-dimensional
AGL	above ground level
AMF	ARM Mobile Facility
ANX	ARM site code for Andenes, Norway
ARM	Atmospheric Radiation Measurement
BNL	Brookhaven National Laboratory
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
COMBLE	Cold Air Outbreaks in the Marine Boundary Layer Experiment
DOE	U.S. Department of Energy
DSD	drop size distribution
ENA	Eastern North Atlantic
eRCA	extended relative calibration adjustment
GE	general mode
HSRHI	hemispherical range height indicator
KASACR	Ka-band Scanning ARM Cloud Radar
KAZR	Ka-band ARM Zenith Radar
KAZRARSCL	Active Remote Sensing of CLouds (ARSCL) product using Ka-band ARM Zenith Radars
LDQUANTS	Laser Disdrometer Quantities Value-Added Product
MD	moderate mode
MDV	mean Doppler velocity
PNNL	Pacific Northwest National Laboratory
PPI/PPIV	plan position indicator
RCA	relative calibration adjustment
RF	radio frequency
RH	relative humidity
RHI	range height indicator
RWP	radar wind profiler
SACRCOR	Scanning ARM Cloud Radar Corrections Value-Added Product
SNR	signal-to-noise ratio
VAP	value-added product
VPT	zenith-pointing mode
WSACR	W-band Scanning ARM Cloud Radar

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1.0 Introduction

The U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) user facility recently concluded its Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE), with its campaign emphasis on marine boundary-layer clouds and mixed-phase clouds during cold-air outbreaks. The COMBLE campaign featured the deployment of the first ARM Mobile Facility (AMF1) to northern Scandinavia (Andenes, Norway), including its standard complement of ARM cloud radars. In keeping with user demands stemming from the previous AMF Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign in Argentina, a post-campaign radar mentor effort was initiated for COMBLE. This activity was intended to improve the usability of the ARM cloud radar data sets in response to overall demands for calibrated, corrected data sets for downstream studies and retrieval applications. In addition to the terrain complexities previously important to CACTI data sets (e.g., clutter designation and/or removal), COMBLE presented new challenges to existing ARM radar mentor capabilities. These included the extension of existing methodologies (e.g., relative calibration adjustment [RCA] target techniques) to frozen environments and the potential issues with their applicability when considering mixed-phase precipitation conditions.

As in the previous CACTI documentation (Hardin et al. 2020), the overall calibration and conditioning process in ARM nomenclature is referred to as generating a "b1" datastream. For the radars, these "b1" standards refer to a datastream that has been calibrated (and cross-calibrated), with effort to deliver the highest-quality (well-characterized) data possible. The "b1" radar mentor reporting (this current document) is intended to detail (i) the status/quality of the original "a1" (raw) data sets during the COMBLE AMF campaign, (ii) the corrections and calibrations that are applied to generate the b1 datastreams available on ARM's Data Discovery, and (iii) the details of the applied methods, e.g., how radar offset/calibration numbers were determined.

1.1 Overview of COMBLE Radars

Three radars were deployed to COMBLE (site code, ANX) at Andenes, Norway. The radars included the Ka-band Scanning ARM Cloud Radar (KASACR) and the W-band Scanning ARM Cloud Radar (WSACR), a co-mounted dual-frequency system, and the Ka-band ARM Zenith Radar (KAZR, a zenith-pointing profiling radar). All radars were installed at the main AMF1 site, as shown in Figure 1. The specifications for these radars are found in Table 1. Figure 2 shows the site's proximity to the coastline, west and north of prominent terrain features. This placement implies that local terrain and sea clutter contaminants are anticipated for lower-tilt radar data sets. Similarly, the ANX location in the northern Atlantic (69.14°N, 15.68°E) is not amenable to previous satellite-based radar monitoring methodologies: therefore, such concepts are unavailable to provide independent references to radar data quality.

Figure 1. ARM radars installed at AMF1 site for COMBLE.

Table 1. Radar specifications during the COMBLE field campaign.

Radar	*Frequency* (GHz)	*Wavelength* (cm)	*Transmit power* (kW)	*Antenna diameter* (m)	*Beam width* (deg)	*Gate spacing* (m)	*Polarization*
WSACR	93.9	0.32	1.7	0.9	0.33	49.96	Horizontal
KASACR	35.3	0.85	2	1.82	0.33	49.96	Horizontal
KAZR	34	0.857	0.187	2	0.3	29.98	Single

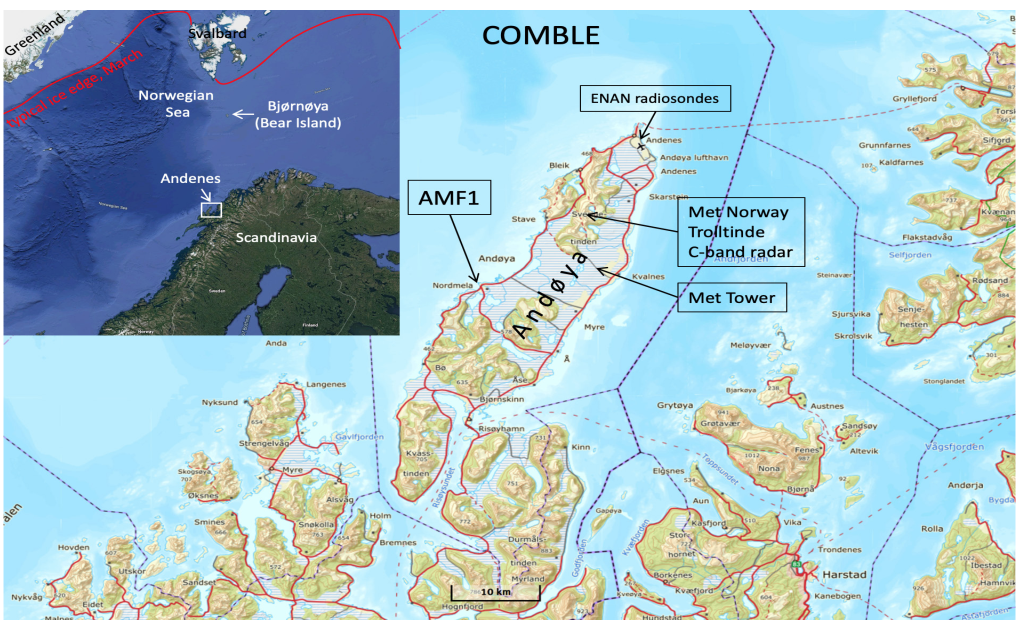

Figure 2. Location of the AMF1 during COMBLE. The topographic map (with terrain heights in m) domain is shown as a white box in the insert image. Also shown are the locations of additional meteorological measurements during COMBLE on Andøya.

1.2 Overview of b1 Processing

As detailed by the previous CACTI report, b1 processing is an activity typically constrained to efforts involving a single (mentored) instrument. Although these efforts perform comparisons against other instruments to obtain information about corrections for an individual b1 datastream, these activities avoid excessive merging of separate ARM datastreams and/or uses of other instruments at processing time. This separation avoids potential circular arguments or assumptions associated with retrieval concepts when establishing radar offsets. As with CACTI efforts, several steps are followed by this b1 processing chain. This section covers those steps relevant to COMBLE at a high level, before describing the various steps in additional detail. A general flowchart of b1 efforts is shown in Figure 3.

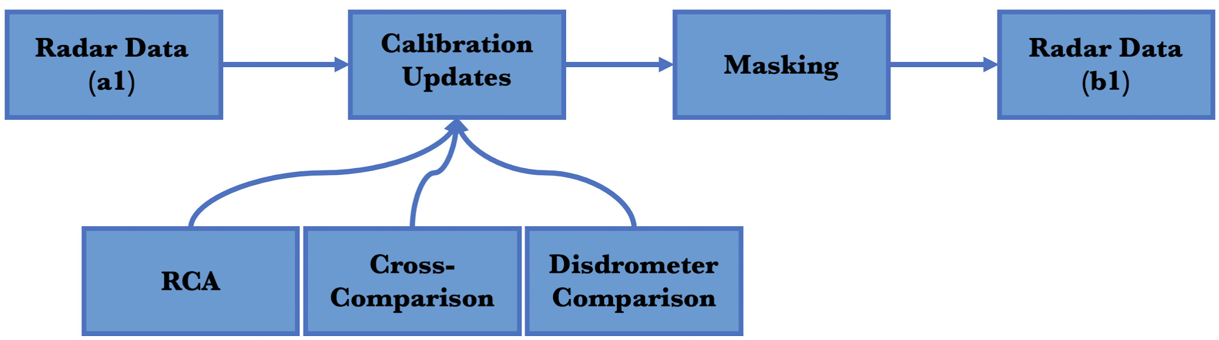

Figure 3. Radar b1 computational flowchart.

1.2.1 Calibration

The primary purpose of the b1 processing is the calibration of the radar datastreams. The calibration of a radar can drift in a variety of ways. The primary function of calibration is to fix the value of the radar constant, C. This constant affects nearly all power measurements the radar takes and represents one of the most dominant sources of errors for the radar. Fundamentally, the radar constant is used as:

$$Z(r_i) = P(r_i) - C + 20log_{10}(r_i)$$

The radar constant C is made up of numerous terms including the finite filter loss, the gain of the antenna, and the wavelength. We can, however, represent it as a constant. Once the constant is solved for, correcting calibration is a linear operation for a given time step. This calibration constant as defined exists for all radars. In the case of the KAZR where pulse compression is used, multiple radar constants are required for each radar mode. Note: the calculations are not always constant in time, as the transmitted radar power, the waveguide loss, and other factors may drift with environmental and/or radar stability changes.

COMBLE calibrations posed additional challenges when compared to previous CACTI efforts because the variety of available techniques for these tasks were limited. Nevertheless, the options enable a solid estimate for radar calibration/offset exceeding most previous ARM campaigns. Similarly, COMBLE employed additional cross-calibration checks that considered all site radars.

1.2.2 Data Quality Masks

In addition to hydrometeors, radars are sensitive to insects, ground clutter, sea clutter, and extraneous radio frequency (RF) interference. It is useful to designate masks that isolate individual or fault conditions in the data. These may serve as an index for when data are good or bad, depending on their usage. For example, a common masking ARM performs with radar data sets is for insects; this mask is not necessarily an indication that insect returns are "bad data" if the user goal is to study clear-air/wind, as insects are often passive tracers of the air motion. Because the processing and measurements vary for each radar, these masks are also individual to each radar datastream.

1.2.3 Data Quality Corrections

In addition to calibration and data quality masks, other circumstances cause poor-quality radar data. Sometimes, these issues (e.g., complete power/site outage) are not correctable, but several issues can be remedied. Wherever possible, b1 efforts correct for malfunctions or misconfigurations of the radar (e.g., as may still be found in a1 or b0 files). When a (known) correction cannot be provided, data quality notes are appended to those data sets and/or described further in this report.

1.3 Radar Performance

COMBLE was highly successful in terms of radar performance and uptime, with all ARM radars operational and in good standing throughout the campaign. Data are available from the KAZR and the WSACR every day of the campaign, and from the KASACR on every day but one. In Figure 4, we show on a daily basis the percentage of radar samples available versus the maximum number of samples expected (for each radar), based on the COMBLE science plan. It is clear that radar operations were quite stable during this deployment.

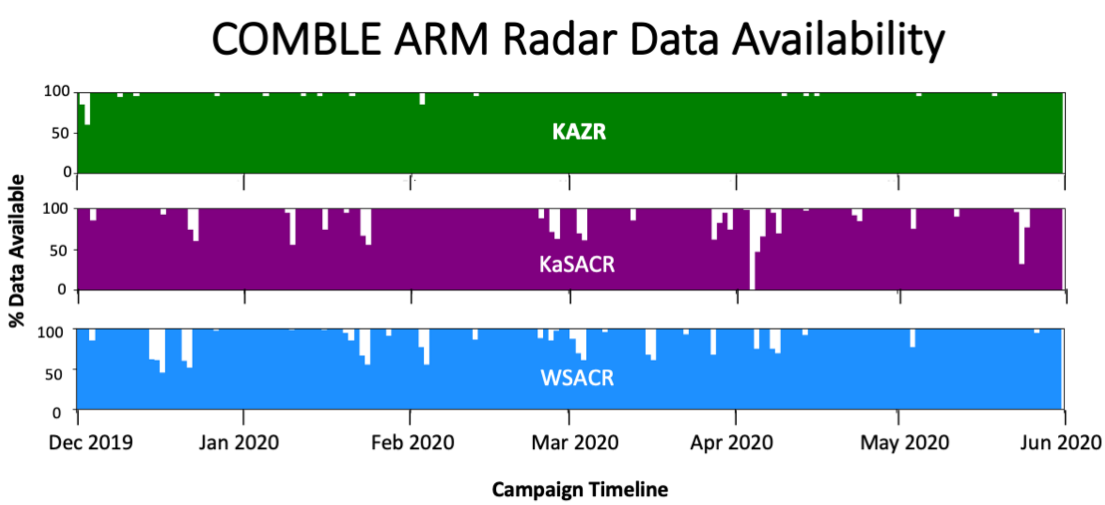

Figure 4. Radar data availability, per day, as a percentage of expected operations. From top to bottom, shown are KAZR, KASACR, and WSACR data availability.

1.4 Scan Strategy

The SACR deployed during COMBLE operated using three scanning modes: a Plan Position Indicator scan, referred to as PPIV, a Hemispherical Range Height Indicator scan (HSRHI), and a zenith-pointing (VPT) mode. *Due to a miscommunication in setting up the HSRHI scanning, the radar did not perform its full hemispheric scanning in elevation (180 degrees), but rather the traditional RHI (0 to 90 degree) operation.* These operations ran from 1 December 2019 to 31 May 2020. Because of the oceanic interest of the campaign, PPI scans did not run a full 360 degrees. Rather, they scanned only a 210-degree sector between 240 and 90 degrees in azimuth. Otherwise, nominal scanning performed as intended. In Figure 5, we show the scan strategy sequencing for the SACR, as well as KAZR, which always pointed vertically.

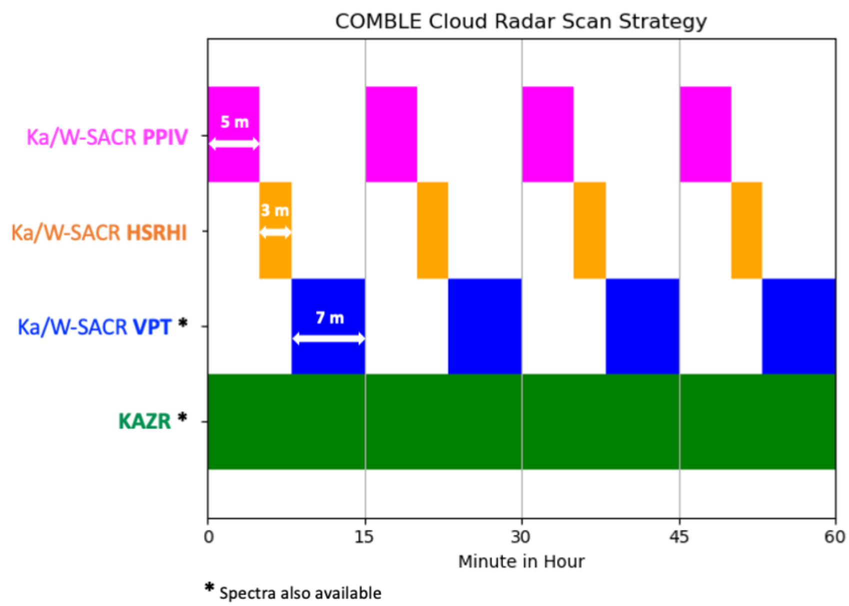

Figure 5. Scan sequencing of ARM radars during COMBLE.

As shown in the figure, each hour began with sector PPIV scans (with tilts at 0, 0.5, 1, and 2 degrees elevation) for five minutes, then transitioned to HSRHI scans at 0, 30, 60, and 90 degrees azimuth for three minutes, and then moved to VPT scans (no rotation, just fixed at zenith) for seven minutes. This 15-minute scan pattern repeated four times per hour throughout the campaign.

2.0 Calibrations and Corrections

The calibration of the radars is a multi-part process that consists of several tasks including onsite measurements of transmit power and receiver calibration. These efforts are typically complemented by a series of calibration scans including “birdbath” (e.g., VPT), scans of a corner reflector, and additional cross-comparisons to ARM and/or partner radars. Owing to issues and limited staffing, these primary mechanisms for calibration were unavailable at the ANX site, including no ability to perform an absolute calibration with RF test equipment (export control limitations). Due to these limitations, radar calibrations during COMBLE are (and must be) based exclusively on relative calibration ideas. This section details select measurements and how/if these informed the eventual b1 calibration.

2.1 Techniques

Several techniques are used to calibrate and correct reflectivity-based variables. The following subsections describe the techniques and how they are applied to the radars.

2.1.1 Corner Reflector Calibration

The previous b1 calibration document developed for CACTI provides a description for end-to-end corner reflection calibration procedures. Although a corner reflector was installed at the ANX location, the scans to perform these calibrations are manually intensive and were unfortunately unable to be performed/scheduled during COMBLE.

2.1.2 Relative Calibration Adjustment

As outlined by the previous ARM radar documentation, clutter around a radar can be used as a relative calibration adjustment target (RCA; Silberstein et al. 2008). ARM has implemented these relative calibration adjustment (Hunzinger et al. 2020) techniques to monitor how drifts in calibration occur in time, showing reasonable success with these ideas during CACTI. Note that RCA activities do not constitute a comprehensive calibration effort; however, one can often combine these efforts with “absolute type” calibrations to inform on radar data quality over extended periods. Importantly, CACTI was also the first effort to validate these RCA ideas for higher-frequency (Ka-band) radars. However, these techniques have only been performed in warmer climates lacking snow cover that may modify the clutter signatures around the radar – thus, variations in snow cover over the duration of the COMBLE campaign could be anticipated as a potential issue for the applicability of RCA methods.

COMBLE adopts the extended RCA (eRCA) techniques that are applicable for PPI/HSRHI data sets. Overall, RCA techniques work by establishing a baseline (daily) reference, with all values relative to this baseline value. For example, an RCA greater than zero means that the daily value is less than the baseline value, or the radar is running “cold”. RCA less than zero means the daily value is greater than the baseline value, or the radar is running “hot”. The values are a direct adjustment, which means that by adding the RCA value back into the reflectivity field, the calibration of that day now matches the baseline day. Typically, if the RCA is stable with time, this implies the calibration offset is also stable with time.

2.1.3 Disdrometer Consistency

RCA application throughout COMBLE (or, during limited windows at the peripheries of the campaign) necessitates pairing these ideas with an ‘absolute’ calibration reference to anchor these relative RCA time series. Since this so-called ‘absolute’ engineering reference was not possible during COMBLE, one relative anchor for calibration offset is to constrain radar measurements to surface disdrometers during liquid precipitation. Applications for these disdrometer reference ideas at cloud radar wavelengths are challenging owing to factors that include radar-surface instrument mismatch, attenuation in rain, and wet radome considerations that promote substantial differences in radar reflectivity Z measurements. Successful applications for these ideas prioritize relatively lighter rain, preferably observations collected close (in time) to surface precipitation onset, to minimize wet radome and attenuation in rain. Yet, light rain conditions unfortunately also challenge disdrometer sampling capabilities owing to smaller, fewer drops (e.g., rainfall rate R < 0.5 mm/hr). COMBLE often sampled shallow marine boundary-layer and stratocumulus conditions known for high droplet concentrations and small/spherical/drizzle drops. These conditions may help mitigate the oftentimes poorer disdrometer sampling in lighter rainfall and balance possible radar wet radome consequences.

Disdrometer-relative comparisons follow certain functional guidelines:

- Isolate disdrometer observations (rain) having low radar reflectivity factor Z (0 < Z < 20 dBZ). Z values should be estimated, as from the ARM Laser Disdrometer Quantities Value-Added Product (the LDQUANTS VAP, with built-in quality control measures) or similar techniques at the corresponding Ka- or W-band wavelengths.
- Identify observations with a sufficient number of drops (i.e., # drop threshold > 50 drops). Lighter precipitation conditions are not uncommon for COMBLE and may be reliably sampled from ground disdrometer equipment, as in existing summaries over the ARM Eastern North Atlantic (ENA) observatory (e.g., Giangrande et al. 2019).
- Comparisons should be performed with vertically pointing SACR and/or KAZR columns well matched to disdrometer 1-minute drop size distribution (DSD) sampling. The radars may be corrected for attenuation in rain using the approximate relationships found in the literature as a function of rainfall rate (e.g., Matrosov et al. 2006). These corrections in light precipitation are minor and often within a few dBZ at Ka-band (i.e., attenuation in Z [dB/km] ~ 0.28*Rainfall_Rate [mm/hr]).
- Gaseous attenuation corrections are not considered significant (Ka-band), but are performed following standard methods employed by ARM in the Active Remote Sensing of CLouds (ARSCL) product using Ka-band ARM Zenith Radars (KAZRARSCL) and Scanning ARM Cloud Radar Corrections (SACRCOR) VAPs.

Previous CloudSat satellite calibration studies over ENA (e.g., Kollias et al. 2019) suggest modest (i.e., within a few dBz) agreement when adopting disdrometer methods and comparing relative offsets to satellite references. This CloudSat study identified the 8th KAZR range gate (i.e., approx. 200-400 m AGL) as useful to balance various radar modes and low-level physical process variability. Additional averaging for these comparisons was also encouraged to reduce instantaneous, physical process variability.

Disdrometer comparisons for this campaign between the KASACR and KAZR unfortunately did not provide a consistent offset value, and varied case to case by upwards of 10 dB (Figure 6) owing to several factors including attenuation in rain, wet radome, and poor disdrometer sampling. Because of the modest ambiguity in applying these ideas, a decision was made not to apply any direct disdrometer comparison values for absolute calibration changes to the radars. We note, however, that in many precipitation events and tests during COMBLE with supporting instruments (i.e., collocated radar wind profiler), a suggested 4-to-6-dB offset was oftentimes consistently required to align KAZR measurements with those reference measurements for radar reflectivity factor.

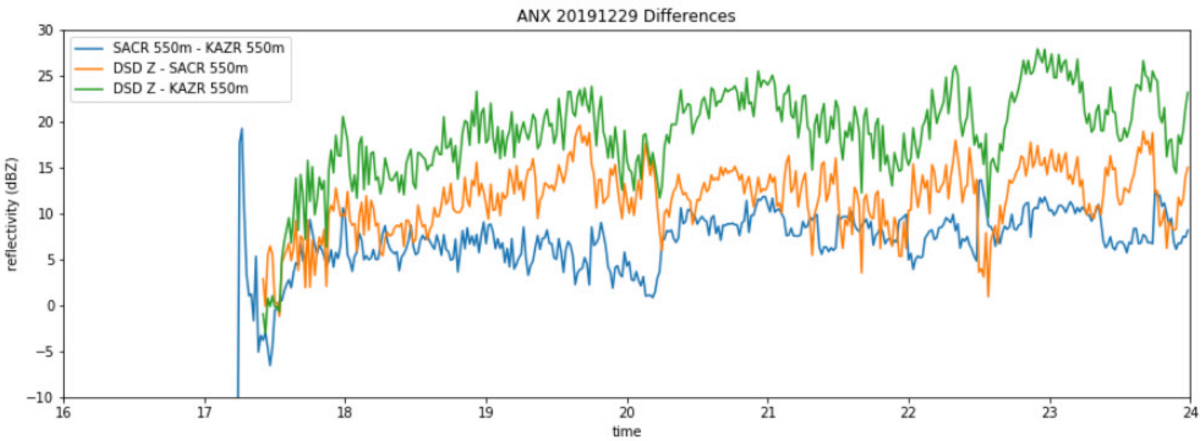

Figure 6. Drop size distribution comparison from a rain case showing the differences in reflectivity between the LDQUANTS DSD reflectivity, KASACR at 550 m, and KAZR at 550 m.

2.1.4 RWP Cross-Calibration

While not pursued by this effort, additional cross-calibration is possible through use of radar wind profiler (RWP) data sets within snow/ice media fields, as well as liquid media as suggested for disdrometer comparisons. Previous ARM activities indicate RWPs maintain relatively stable performance over extended campaigns when anchored to nearby disdrometer records. Unlike cloud radar wavelengths, RWPs reduce wet radome concerns and are not susceptible to significant attenuation in rain. Thus, these radars enable reflectivity factor Z estimates (if Rayleigh) within 2-3 dBZ. Note, direct RWP Z comparisons to the cloud radars within rain is often not straightforward, since Z measurements at Ka-band do not adhere to Rayleigh scattering assumptions, and are attenuated in rain. Similarly, Ka-band radomes may retain water in/near rainy conditions, which also attenuates the measurements.

However, RWP measurements may provide value if used in snowy conditions during COMBLE. Factors such as wet radome and attenuation in precipitation may be significantly reduced when considering snowfall. Ka-band reflectivity factors under lighter snowfall conditions should more closely adhere to Rayleigh assumptions, and thus be amenable to comparisons with calibrated RWP Z estimates. It would nonetheless be advisable to avoid heavy snowfall, and to monitor snow accumulation/melt on the radome; this includes shifts associated with snow removed by technicians or subsequent rain events. As noted for disdrometer comparisons, there was typically a 4-to-6-dBZ offset between calibrated RWP observations and those from the KAZR in limited testing from COMBLE events.

2.2 SACR Calibrations and Corrections

The KASACR and WSACR operated well throughout the campaign (up time), as described in the previous sections. The RCA method was performed on KASACR data sets relative to the PPI mode, due to the clear and abundant clutter signature. This RCA effort was also modified for other modes (e.g., RHI) as a basis for eventual clutter masking.

The composite clutter map used for RCA calculation is shown in Figure 7. Similarly, Figure 7 shows KASACR daily median RCA after applying a relative humidity and attenuation filtering (previously discussed in the CACTI reporting). The mean RCA for all of the days in the campaign was found to be 0.88 dB. A subset of daily RCA values are shown in Figure 8, representing the relative calibration value of the radar on days when primarily rain was falling (as opposed to mixed-phase or frozen precipitation). The mean for these 'rain-only' cases was approximately 1 dB. Because of this, we are selecting a value of 1 dB to represent the RCA offset starting point for the COMBLE campaign. Again, this RCA value/trend does not imply the radar was only offset (in magnitude) by 1 dB; however, the stable RCA behavior suggests the drift of the radar offset was minimal and potentially within 1 dB. This implies we should expect to estimate similar offsets (as compared to disdrometer or other reference) in rain at various points throughout the campaign and/or a single calibration offset would be sufficient for most applications.

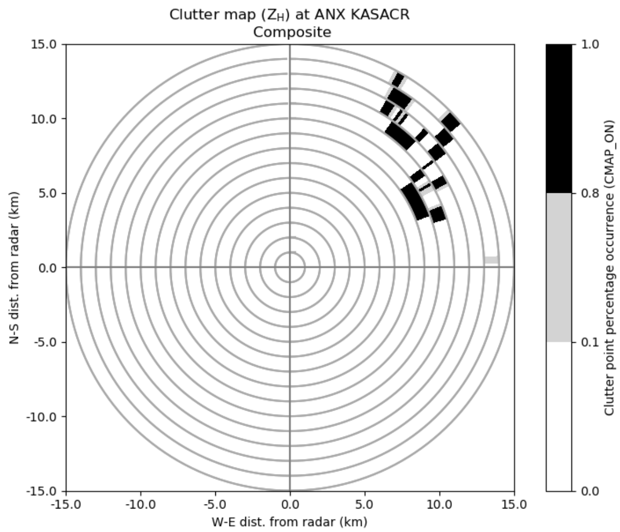

Figure 7. Composite clutter map for KASACR at the ANX site during COMBLE.

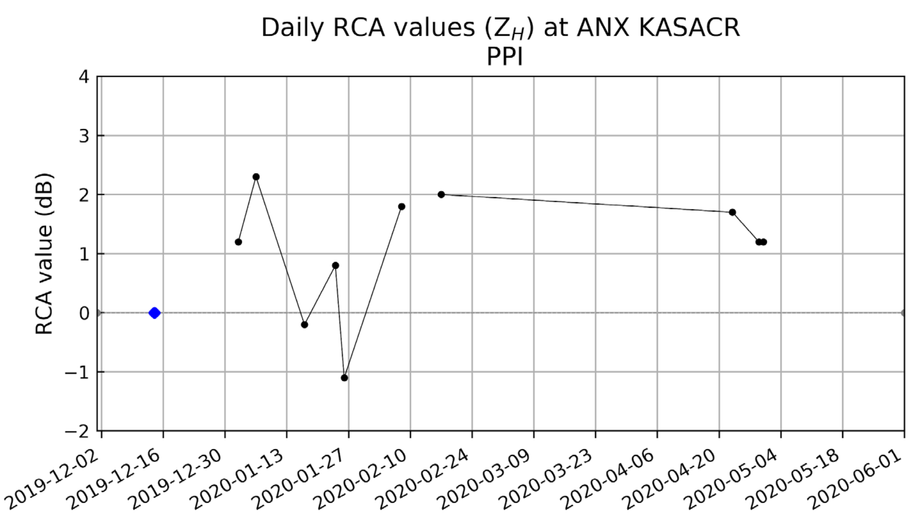

Figure 8. Daily RCA values from a subset of campaign days identified as rain events.

2.3 KAZR Correction

The Ka-band Zenith ARM Radar (KAZR) is a vertically pointing radar with specifications given in Table 1. It operates using two different pulses. The first is a long chirped pulse, referred to as the moderate or MD mode, with pulse compression applied to give a much higher level of sensitivity. This does, however, introduce an increased blind range, as the radar cannot see while it is transmitting. There is also a short pulse mode, referred to as the general or GE mode, that provides returns closer to the ground. The KAZR at the COMBLE site does not have polarimetry. Calibration focuses on these two pulse modes exclusively. For the purposes of this calibration, we compared the KAZR modes to each other (GE and MD) and cross-compared the GE mode with the KASACR and XSACR.

2.3.1 Cross-Comparisons with KASACR

Originally, the KAZR was cross-compared with the KASACR. This was done by using the HSRHI and VPT scans from the KASACR, sub-setting the HSRHIs to pull out only the rays within one degree of vertical, and then directly cross-comparing these with the KAZR. The KAZR and KASACR do not have coincident range grids, so to compare the points, each KASACR ray was interpolated to a common range grid with the KAZR. Visual inspection of the results showed negligible influence on the actual values due to the interpolation.

Next, we applied a selection filter to the data to control for the differing sensitivity of the radars and selected only good meteorological signal as much as possible. The filters we used were a signal-to-noise ratio (SNR) greater than 0 and reflectivity between -5 and 15 dBZ. Only points that were identified as "good" in both the KAZR and KASACR using the filters were used for comparison. A file was output that contained the SACR file date and time, mean offset, median offset, and number of points used in the comparison. We then filtered the data to only include times when the relative humidity (RH) was less than 60%, as we found that the KAZR was affected quite heavily by humidity and condensation (Figure 9), similar to our findings during the CACTI b1 process.

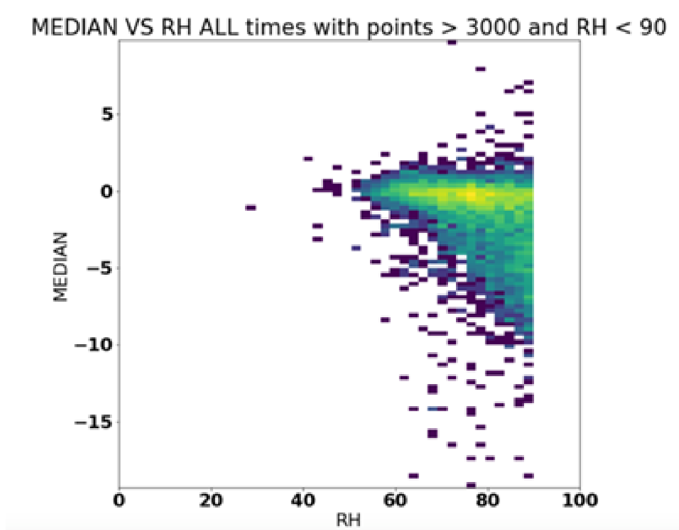

Figure 9. 2D histogram showing the relation between RH and the median daily offset between KAZR and KASACR. As was seen in CACTI, there is a drop in variability in the offset around 60-70% RH.

The resulting offset between the general GE mode and the KASACR reflectivity at vertical incidence was 0.35 dB at low relative humidity levels, although there was some variability on some days. (Figure 10).

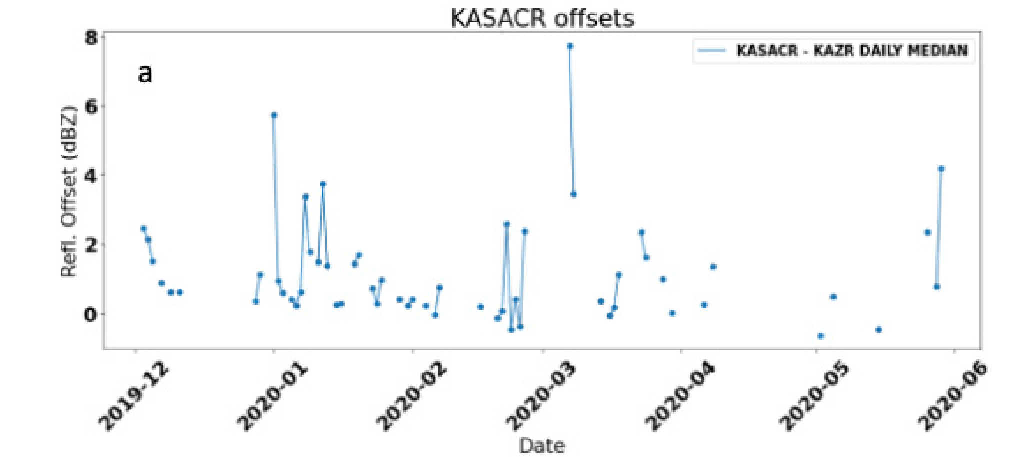

Figure 10. The KASACR versus KAZR median daily offset. While the offset varied day to day, the mean in times of low surface relative humidity was -0.35 dB.

2.3.2 Cross-Comparisons with WSACR

Next, the KAZR was cross-compared with the WSACR. This was done in a similar method to the KASACR comparison, as described above, with the same filters applied to the data.

The resulting median offset over the campaign between the general GE mode and the WSACR reflectivity at vertical incidence was 1.4 dB at low relative humidity levels, although there was some variability. (Figure 11).

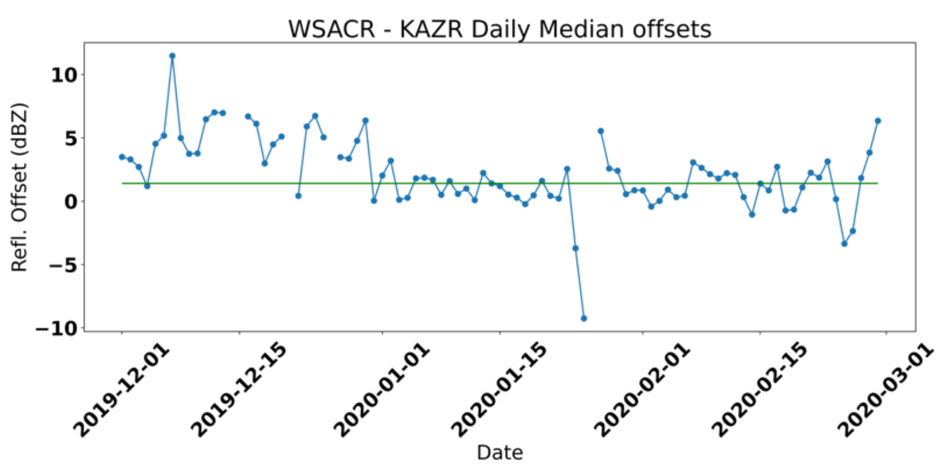

Figure 11. The WSACR versus KAZR median daily offset. While the offset varied day to day, the mean in times of low surface relative humidity was 1.4 dB.

2.3.3 KAZR Intermode Comparison

Next, the calibration of the general GE mode can be used as a reference for comparison with the moderate mode (chirped pulse). We follow a similar method to the above to cross-compare the two modes.

First, we interpolated the GE mode data to match the MD mode. The data were then filtered for SNR greater than 0 and reflectivity between -15 and 5 dBZ. Only points that were deemed "good" in both the GE and MD data were used for comparison, and a file was output containing the date and time, mean, median, and number of points used for comparison.

Once this file was created, the data were plotted. Figure 12 shows little variability day to day. We can see much smaller variability as compared to the cross-calibration with KASACR, which is also expected due to the smaller number of differing factors in this analysis. We then took the median of all files with more than 1000 points used for comparison at each relative humidity between 40 and 60% for consistency with the method applied when comparing KASACR and KAZR GE reflectivities, and found that the mean offset of this was 1.6 dB. As this was the same KAZR deployed to CACTI, it is encouraging to see the offset between the modes agree at the two sites.

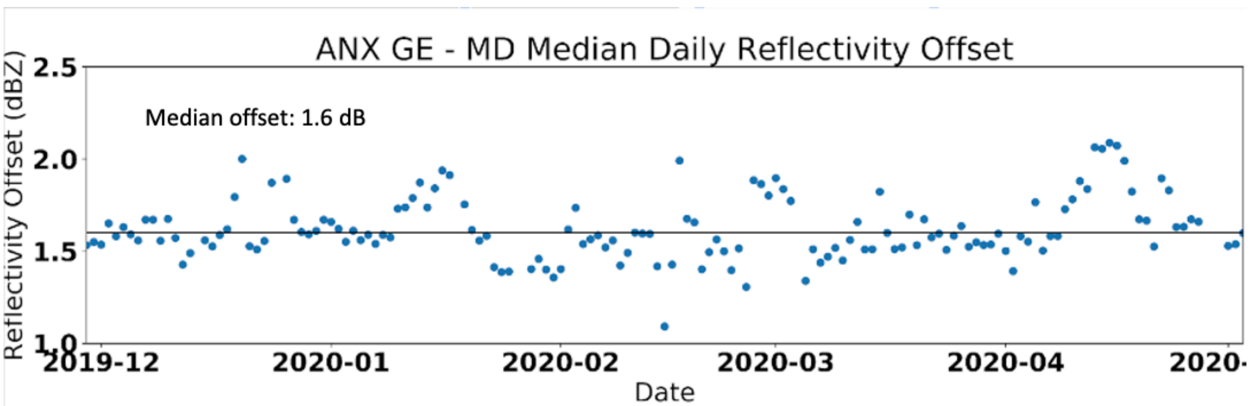

Figure 12. KAZR GE versus MD comparison, showing much less variability than the KASACR versus KAZR comparison shown previously.

3.0 Masks and Post-Processing

3.1 SACR Mask and Post-Processing

The SACR does not contain any built-in masks, so simple masks were added to the b1 files. The first mask consists of an SNR mask that helps to differentiate between returns and noise. The second mask is a ground clutter mask based on typical non-meteorological and stationary returns of radar variables, intended to identify the primary locations where ground contaminants may alter the measured radar quantities. Variables and their corresponding thresholds for ground clutter selection are found in Table 2. The application of these masks depends on the usage of the data, so no data have been removed, but the masks are available in the file as a first pass at significant echoes for climate applications. Additional processing for attenuation correction (gaseous) is performed in SACRCOR VAP datastreams.

Table 2. Thresholds of radar variables for clutter selection.

Radar variable		Clutter threshold	
Name (Abbrev.)	Unit	Minimum	Maximum
Reflectivity (Zh)	dBZ	10.0	--
Mean Doppler velocity (Vr)	ms-1	-0.1	0.1
Linear depolarization ratio (LDRv)	dB	--	0.0
Signal-to-noise ratio (SNR)	dB	0.0	--
Copolar to cross-polar correlation coefficient (ρhx)	--	0.4	1.0

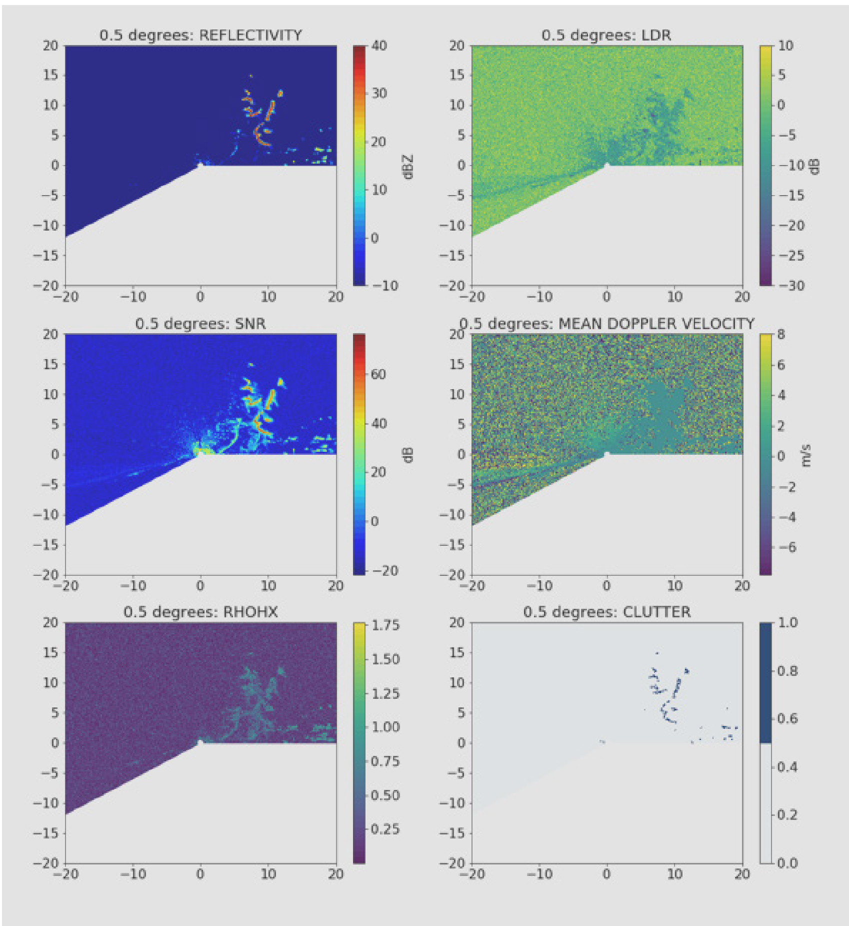

Figure 13. Sample KASACR 0.5 degree PPI scan at ANX on a clear (no precipitation) day with clutter signatures visible in each radar variable. Top: reflectivity, LDR; middle: SNR, mean doppler velocity; bottom: co-to-cross-polar correlation coefficient, gates identified as clutter using thresholds in Table 2.

3.2 KAZR Masks

KAZR masking is a simple SNR filter for SNR > 0. Additional post-processing to include more precise significant detection masks and gaseous attenuation correction is available in the KAZRCOR VAP datastreams.

4.0 Description of Data Files

This section contains a description of *some* of the more relevant parameters and variables in the radar datastreams.

Table 3. Variables of SACRs and KAZR.

Key
New variable calculated
Correction applied
New variable and correction applied

SACR File Contents	
Moments	
co_to_crosspol_correlation_coeff	Copolar to cross-polar correlation coefficient (RhoXH)
crosspolar_differential_phase	Cross-polar propagation phase shift
linear_depolarization_ratio_v	Linear depolarization ratio, vertical channel
mean_doppler_velocity	Radial mean Doppler velocity, positive for motion away from the radar
reflectivity	Equivalent reflectivity factor, with offset applied
signal_to_noise_ratio_copolar_h	Signal-to-noise ratio (SNR), horizontal channel
signal_to_noise_ratio_crosspolar_v	Signal-to-noise ratio, vertical channel
spectral_width	Spectral width
Masks	
censor_mask	Bit mask 0: no mask 1: SNR < 0

KAZR File Contents	
Moments	
linear_depolarization_ratio	All values set to nan. This variable is not present in this KAZR.
mean_doppler_velocity	Radial mean Doppler velocity, positive for motion away from the radar
mean_doppler_velocity_crosspolar_v	All values set to nan. This variable is not present in this KAZR.
reflectivity	Equivalent reflectivity factor, with offset applied
reflectivity_crosspolar_v	All values set to nan. This variable is not present in this KAZR.
signal_to_noise_ratio_copolar_h	Signal-to-noise ratio (SNR), horizontal channel
signal_to_noise_ratio_crosspolar_v	All values set to nan. This variable is not present in this KAZR.
spectral_width	Spectral width
spectral_width_crosspolar_v	All values set to nan. This variable is not present in this KAZR.

5.0 Unusual Mean Doppler Velocity Patterns: A Brief Discussion

In COMBLE, several events collected some intriguing Doppler signatures, with larger-scale shifts in adjacent upward and downward motions in clouds. For most times, the downward motions caused by the falling hydrometeors are expected. Initially, these abnormal upward and downwards swings in velocities were thought suspiciously due to the radar hardware issues, or mis-pointing of the radar in the vertical (i.e., horizontal winds projected into the vertical). However, no radar hardware system issues were found during the period, radar technicians indicated that the radar pointing was generally confirmed on a regular basis, and both the KAZR and the KASACR radars showed these consistent features in the cloud field (as well as other vertically pointing RWP). The team speculates that these adjacent vertical motions appear to be caused by the environmental southwest flows (strong or weak), potentially over the elevated terrain southwest of and adjacent to the mountains (Figure 2). These newly discovered upward motions need further investigations from the scientific community, but we caution that larger-scale (order of hours) shifts in vertical motions may be attributed to terrain contamination rather than a radar hardware, cloud dynamical, or microphysical explanation.

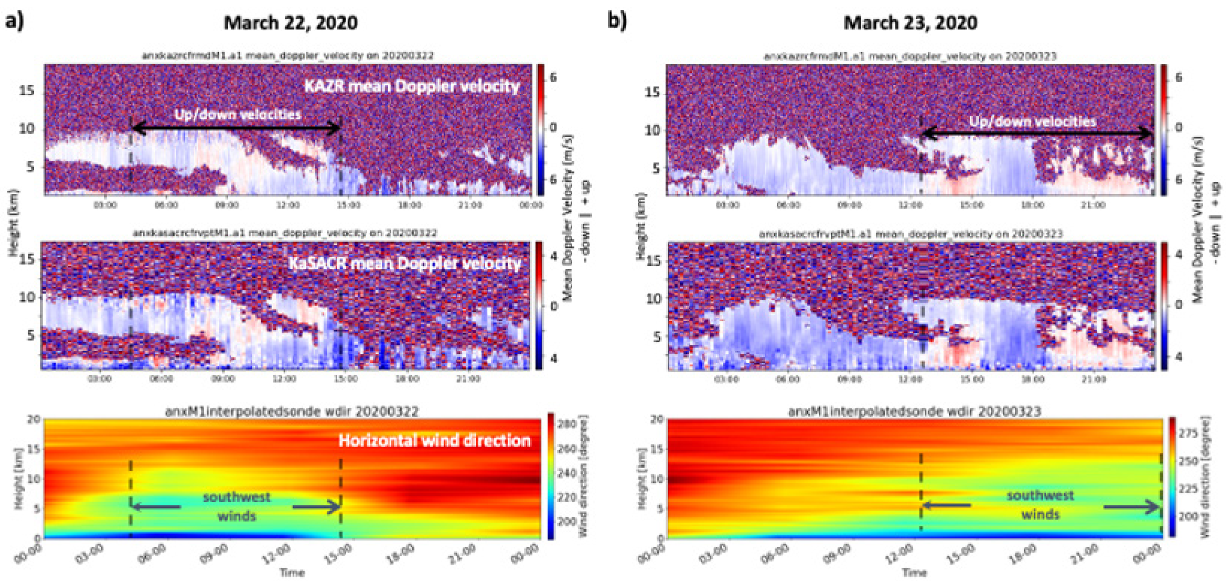

Figure 14. Adjacent-in-time regions of upward and downward mean Doppler velocities (MDV) are occasionally observed during the COMBLE deployment by both the KAZR and KASACR cloud radars. This phenomenon appears to be caused by southwest flow over the elevated terrain southwest of and adjacent to the Andenes, Norway site (refer to Figure 2 topographic map). Panel a) shows, top to bottom, KAZR MDV, KASACR MDV, and interpolated sounding wind directions for March 22, 2020. Panel b) shows the same three figures for March 23, 2020.

6.0 References

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