U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-TR-212

ARM Radar Science Recommendations from 2017 6th ARM Radar Workshop

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March 2018

ARM CLIMATE RESEARCH FACILITY

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

Acronyms and Abbreviations

3-D	three-dimensional
ACE-ENA	Aerosol and Cloud Experiments-Eastern North Atlantic
ADC	ARM Data Center
AERI	atmospheric emitted radiance interferometer
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remote Sensing of Clouds VAP
BNL	Brookhaven National Laboratory
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CFAD	contoured frequency by altitude diagram
CMAC	Corrected Moments in Antenna Coordinates VAP
CRM	cloud-resolving model
DOE	U.S. Department of Energy
ENA	Eastern North Atlantic
GCM	Global Climate Model
GPM	Global Precipitation Measurement
IOP	intensive operational period
KAZR	Ka-Band ARM Zenith Radar
KAZR2	Ka-Band ARM Zenith Radar–Second Generation
LASIC	Layered Atlantic Smoke Interactions with Clouds
LES	large-eddy simulation
MARCUS	Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean
MASC	multi-angle snowflake camera
MMCR	millimeter-wavelength cloud radar
NSA	North Slope of Alaska
OLI	Oliktok Point, Alaska
PI	principal investigator
PIP	precipitation imaging probe
RWP	radar wind profiler
SACR	Scanning ARM Cloud Radar
SACR2	Scanning ARM Cloud Radar–Second Generation
SACRCOR	Scanning ARM Cloud Radar Corrected Moments VAP
SNR	signal-to-noise ratio
VAP	value-added product
XSAPR	X-Band Scanning ARM Precipitation Radar
XSAPR2	X-Band Scanning ARM Precipitation Radar–Second Generation

Contents

1.0 Introduction

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility's radar organization was formed to provide an integrated approach to meet the scientific objectives of ARM. The radar organization consists of two groups: Radar Science and Radar Engineering and Operations. The two groups work closely for planning, coordination, and communications to produce high-quality observations and products from the ARM radar network, which consists of complex radars deployed in very challenging environments. In addition, scanning cloud radars are relatively new in the community, with very limited products that are mature enough to be applied for modeling studies. The Radar Science Group and Radar Engineering and Operations Group meet regularly along with researchers and users from the community in a workshop. The overarching objective of the workshop is to maximize the usage of ARM radar data for improving our understanding of processes and, ultimately improving representation of clouds and precipitation in models. The 6th DOE ARM Radar Engineering and Radar Science Workshop was held October 24-26, 2017, at Stony Brook University. Approximately 40 participants were present; a detailed list of participants is listed in Section 5.

This report documents recommendations made by members of the science community who attended the workshop. Their recommendations appear italicized in the report. ARM management will consider these recommendations in their future planning and prioritization activities. The topics addressed during the workshop are contained in the agenda (Section 4). Significant action items, recommendations, and comments that came out of the meeting are contained in Section 3. The content in Section 3 presents a path through important discussions that were pursued during the Workshop.

2.0 Action Items, Recommendations, and/or Comments

2.1 Miscellaneous Topics

2.1.1 ARM Unique Assets

It is important for ARM to distinguish itself from other observational facilities in order to increase its user base.

One distinct strength of the ARM radar systems is their ability to collect multi-frequency observations in the column. ARM also collects fully polarimetric scanning observations. Both are collected in conjunction with surface precipitation measurements, which facilitates their interpretation.

ARM has the ability to collect 3-D observations of warm clouds. In addition, while it is not currently exploiting it, ARM has the ability to track individual clouds and storms.

Other assets of ARM include its ability to collect cloud and precipitation observations within a few hundred meters from the surface, at a few tens of meters resolution.

Finally, ARM observations are collected continuously, enabling diurnal cycle and life cycle analysis.

2.1.2 Radar Science Mission and Scope

Ideally, scientific objectives should motivate operation of the ARM radars. This connection between specific radars and their scientific mission is sometimes vague. This may also be the result of significant downtimes for many of the radar systems in the past.

Radar Science will recommend science objectives for current ARM radar system configurations and locations. This information will contribute to the radar mission statements, which will be developed by the ARM Radar Engineering and ARM management teams. Timelines and objectives will be consistent with ARM and DOE mission and priorities.

2.1.3 Instrument Handbooks

Instrument handbooks are the first tool to which scientists turn to familiarize themselves with new instruments, their data sets and their processing. Incomplete or outdated handbooks lead to confusion, misinformation, and potentially to the loss of users.

In order to reach more users and reduce confusion, Radar Science supports ARM's current efforts to update and maintain all instrument handbooks.

2.1.4 Calibration and Uncertainty

Radar reflectivity and polarimetric variables require calibration to render maximum scientific value. Calibrated data are necessary for the production of value-added products such as Active Remote Sensing of Clouds (ARSCL) and reflectivity contoured frequency by altitude diagrams (CFADs) for model comparisons. These products are currently being produced despite the lack of calibrated data. As a result, some users may come to mistrust ARM radar calibration.

Radar Science suggests labelling the reflectivity field in ARSCL and ARM CFADs as "questionable/uncalibrated" until calibration is performed. ARSCL remains a valuable product for cloud boundary location and should remain in production.

The topic of calibration comes up every year and progress is being made on determining methods that can assist in achieving calibration. Several calibration techniques were presented during the workshop. The engineering group has built portable test equipment to perform calibration. Corner reflectors are still being used to calibrate certain Scanning ARM Cloud Radars (SACRs) but have not been installed at all sites. Moreover, calibration using corner reflectors cannot be achieved under all conditions. To be effective, corner reflector calibration requires no wind and no rain. This entails that calibration remains somewhat of a manual process and should not/cannot be performed on every radar heartbeat. However, corner reflector data can be collected daily and then post-processed as needs be retrospectively.

The group would like calibration corner reflector scans to be performed once a day. The engineering group should assess the feasibility of the procedure.

Radar Science suggests archiving the calibration files for traceability.

Vicarious calibration techniques were also discussed. For instance, ice clouds have been proposed as natural targets for calibration. While this technique is effective, it requires specific atmospheric conditions. Finally, it has been suggested that CloudSat overpasses could be used for ARM radar reflectivity calibration. CloudSat is considered by many as being calibrated to within 0.5-1.0 dB.

These various calibration techniques could be sufficient to calibrate ARMs radars; however, it remains unclear which technique is more reliable under which conditions and how the retrieved calibration offsets should be applied, archived, and described.

There is a need to create a workflow for radar calibration. This workflow should describe the various calibration techniques and their applicability. It should also describe how the final "best estimate" calibration constant will be estimated, including its temporal validity. The workflow should describe where the calibration constant will be placed (e.g., in radar files) and where the information describing the calibration techniques will be found (e.g., in instrument handbooks).

Radar Science would like the calibration process to be reversible as much as possible. However, it is understood that for value-added products that merge multiple modes, such as ARSCL, one calibration constant may be applied to each mode making the reversal complex.

At the moment, the various calibration techniques can only help us gain confidence in uncalibrated radar data. For instance, confidence is gained if all calibration techniques indicate that current data have no offsets. Perhaps radars with time periods of consistent calibrations could be labeled as data epochs.

Both natural targets and CloudSat could be used to calibrate historical data.

It remains unclear whether the program wants to calibrate its historical data. This would involve the reprocessing of several data files. Hopefully, the new computer infrastructure of ARM could accelerate this process. If ARM decides to pursue calibration of its historical radar data, a good starting point may be consideration of calibrating millimeter-wavelength cloud radar (MMCR) data based on Karen Johnson's prior work on this subject together with Michele Galletti's work demonstrating how to make mode calibrations consistent though not tied to an absolute calibration. Perhaps historical data calibration can be tied to CloudSAT vicarious absolute calibration back to 2006.

2.1.5 Data Labeling

Users would like clarification on the 'missing data' label and suggest a label be provided about why data is missing if known (such as 'in transit' or 'misplaced').

2.1.6 Clutter Mitigation

Clutter is an issue for the KAZR2 at Oliktok Point, Alaska (OLI) and the Eastern North Atlantic (ENA) observatory. The engineering group has installed a "homemade" clutter fence at OLI to test its efficacy in reducing clutter. The fence is quite effective at reducing clutter, but its effect on the antenna beam pattern has not been evaluated. In addition, this clutter fence accumulates snow and may also affect the radar antenna.

Clutter mitigation post-processing is a very tedious process. As such, the group argues for keeping the "homemade" clutter fence despite its effects on the antenna. Perhaps the fence should be moved back *slightly to reduce snow accumulation. Alternative engineering solutions for clutter mitigation pre-processing should be investigated.*

Christopher Williams proposed a post-processing technique for clutter mitigation using radar Doppler spectra. Scott Giangrande and Edward Luke will work with Christopher Williams to incorporate this technique into the MicroARSCL VAP.

Radar Science recommends that one filtering algorithm be used for clutter removal in all radar data. This will reduce duplication of effort.

Recommendations were made for Radar Engineering to pursue simple tests with the Ka-Band ARM Zenith Radar–Second Generation (KAZR2) to determine if internal hardware configurations are responsible for the clutter.

2.2 Data Products

2.2.1 .b1-Level Data Products

.b1-level data consist of calibrated (for reflectivity and polarimetry) and noise-filtered data fields. Ground-clutter mitigation will also be implemented by Radar Engineering and included within .b1-level files. .b1-level data will be produced only for well-characterized systems that includes all future radar data and only for ENA and OLI historical data. .b1-level data will be produced with a three-month time lag. The first wave of .b1-level data are ready for evaluation.

Evaluation .b1-level data should be moved to the evaluation product area of ARM to make the review process transparent and allow the monitoring of users who access the data.

There is a need for a K_{dp} *product. Radar Engineering is working on it and perhaps such a product will one day get into level b1. This was the only data product discussed during the meeting as one not currently in level b1 that needs to make its way into level b1. The relationship between level-b1 file content from Radar Engineering and the capabilities/content of CMAC2.0 was not clear as the workshop came to an end.*

The variables that will be included in the .b1-level data files should be listed and shared on Trello or in an easily editable document for final comments/approval. This should be done for each radar and radar generation independently.

.b1-level data processing will not use other data sets. As such, gas attenuation will not be part of .b1-level data processing.

2.2.2 ARSCL Reprocessing

ARSCL is a value-added product that combines multiple data streams, including two vertically pointing radar transmitting modes. Unfortunately, reflectivity in the two radar modes is sometimes inconsistent, creating artifacts. In addition, ARSCL still contains insect and other clutter at several sites. Scientists have proposed techniques to mitigate these issues.

It is suggested that each KAZR mode should be calibrated independently before a reprocessed version is created. Consistency between modes is desirable to avoid artificial artifacts where modes are merged. Making mode calibrations consistent might follow the proposal outlined by Michele Galletti during his time at Brookhaven National Laboratory (BNL).

Clutter and insect mitigation should also be refined before ARSCL reprocessing. MicroARSCL, which relies on Doppler spectra, could be used to assist in clutter and insect mitigation.

2.2.3 MicroARSCL

MicroARSCL is a value-added product that is currently under evaluation. It is based on radar Doppler spectra data corrected for noise and artifacts before information about the moments in the Doppler spectra are extracted.

MicroARSCL algorithms are mature and, as such, Radar Science suggests that MicroARSCL be moved from evaluation to production.

MicroARSCL is produced using objective processing; as such, it could be used to produce .b1-level spectra. This would eliminate the need to develop alternative algorithms for the production of .b1-level spectra and avoid effort duplication.

2.2.4 CMAC 2.0

CMAC 2.0 is a value-added product that provides post-processed precipitation radar data.

CMAC 2.0 should be moved from evaluation to production.

2.2.5 Forward Simulators

Various forward simulators were presented during the workshop. Simulators have been developed for large-eddy simulation (LES) and cloud-resolving models (CRMs) and more recently for global climate models (GCMs). Three common research themes around simulators include:

1. Best techniques to convert model outputs to radar observables. Which scattering library or retrieval technique will produce the most accurate results with the fewest assumptions?
2. Uncertainty quantification. How can uncertainty in the forward simulator be quantified? Should multiple forward simulator realizations be performed using variations on the scattering assumptions?
3. Best techniques for statistical resampling. Are CFADs the best way to summarize results? Should attempts be made to separate cloud types or capture diurnal cycles?

The value of a lidar simulator for phase retrieval was also discussed. There are currently no explicit plans for ARM to develop a lidar simulator for GCMs.

There is a consensus that the observational benchmarks created for model evaluation should be constructed using calibrated and noise-, clutter-, and insect-filtered data.

2.2.6 VAP Evaluation

Translators and developers are not receiving the feedback they expect/require to evaluate value-added products. The lack of feedback does not seem to be attributable to the lack of interest of users in the products developed, which would mean that ARM is not focusing its efforts on the right products. Rather, it is because most of these products produce quality-controlled data rather than retrieved geophysical quantities of interest. These products are still needed as they are a stepping stone to geophysical retrievals.

ARM should begin production of level-b1 radar data products as soon as possible so that downstream processing of data quality-controlled products that focus on geophysical retrieval products (e.g., Scanning ARM Cloud Radar Corrected Moments [SACRCOR], Corrected Moments in Antenna Coordinates [CMAC]) can get underway. Essentially, the scientific community is most interested in geophysical retrieval products.

Another reason for the lack of feedback is a lack of time/interest from the most knowledgeable users. Knowledgeable users tend to produce their own versions of a product rather than using the ones produced by ARM.

A path forward for receiving feedback from expert users could be to collect output from their versions of a product and for the translators and developers to perform the evaluation of these products. If differences are identified, the expert users should assist the translator/developer teams by providing code and/or advice on how to resolve the discrepancies. Also, expert users need to be constantly encouraged to provide feedback to ARM translators as soon as they identify potential issues in ARM data products. Waiting until science team meetings to convey such information wastes time and does not always lead to productive outcomes.

2.3 Sensors

2.3.1 X-Band Network

A lot of engineering effort has gone into refurbishing the X-Band Scanning ARM Precipitation Radar (XSAPR) network. This network was recently redeployed at the SGP. The rapid expansion of the SGP wind farm put the value of the X-band network into question. Lessons learned with respect to multi-Doppler retrievals also indicate that, as it is currently operated, the network may not provide adequate data for model evaluation. Despite this, multiple participants showed interest in using the XSAPR network; however, some suggest altering its scan strategy. Proposed scan strategies vary from sit and spin to cell tracking to vertically pointing.

A white paper proposing various intensive operational period (IOP) or scan strategies will be drafted and delivered to ARM for consideration. Depending upon white paper content, one or more IOPs may emerge from it.

2.3.2 W-Band Radars

Analysis of historical W-band radar data shows promise at high latitudes especially in combination with other radar frequencies. However, in warm clouds the ability of W-band radar to penetrate clouds and light precipitation is limited. W-band sensitivity is further decreased when scanning due to increased path length.

Radar Science suggests putting all warm climate W-band radars, such as the one at ENA, to vertically pointing mode. If the Ka-band is to scan, the W-band could be unmounted from the scanning pedestal and placed on an independent stand.

Valuable liquid water content retrieval research is still ongoing and requires more Ka-W SACR data. The SACR2 at ENA with its slaved clocks and matched beams is the ideal sensor for such research.

Radar Science suggests keeping the Ka-W SACR2 radar at the ENA for an additional 6 months until the necessary data are collected. These data would be mostly continuous vertical dwells with scanning done from time to time in an IOP-like framework. ENA is the preferred site since at this site clouds are bigger and high in liquid water content, facilitating their detection. After the six-or-so-month period of data collection, the previous point about separating the ENA W-band from the scanning Ka-band radar might be considered.

2.3.3 Radar Wind Profiler

In order to capture storm vertical structure and coherency, as well as horizontal shear, there is a need to adaptively switch between radar wind profiler (RWP) modes.

There is a lot of disagreement about this because there are competing science objectives related to this issue, which is why it was put on hold. The original proposal was driven by the mentor. Any changes to RWP scans should be driven by the science goals with consultation with mentors on instrument limitations and capabilities. Radar Science suggests continuing discussions among all vested participants until a decision can be made. Perhaps an IOP of some sort might be proposed as a test sometime in future.

2.3.4 KAZR2

Scott Giangrande and the BNL team will investigate the reasons for power streaks close to the surface in KAZR2 data. These streaks reduce sensitivity to -45 dBZ close to the surface. Perhaps the chirp mode may be affecting the burst mode, leading to these streaks.

2.3.5 SACR2

High signal-to-noise ratio (SNR) is required when collecting polarimetric observations. In its current set up, the high-latitude SACR2 does not achieve the SNR required to fulfil scientific objectives.

Radar Science proposes to scan at higher elevation angles to reduce the path length and capture cloud tops at higher SNR. The lowest PPI scan at OLI is at 1 degree, which is perhaps too low and should be revisited upon installation at Barrow.

2.3.6 Ancillary Sensors

Research using radar data often involves the use of additional sensors, especially lidars and radiometers. At the moment, many group members are experiencing difficulty in keeping track of instrument issues.

There was a discussion as to whether Trello should capture concerns regarding these instruments. This would involve more instrument mentors to start using Trello.

Some members also expressed a desire to closely collaborate with the lidar mentors/group to improve lidar data quality.

Surface snow measurements are essential for the interpretation of radar and tethered balloon data.

Ideally, both the NSA and OLI sites should have surface snow measurements (precipitation imaging probe [PIP] and multi-angle snowflake camera [MASC]). However, in the event where only one system is available, it should move with the SACR2 system, which is being relocated from OLI to NSA. The relocation of the snow surface measurement sensors should not take place immediately but rather after the upcoming winter since the OLI Science Team would like to collect more data this winter.

Aerosol measurements are useful to evaluate and develop microphysical parameterizations.

Raman lidar moisture profiles (and atmospheric emitted radiance interferometer [AERI] temperature/moisture retrievals) would be valuable for warm cloud studies.

Delays in data product release should be reduced as much as possible.

2.4 Campaigns

2.4.1 MARCUS

Scientists would like the raw data to be made available after every leg versus after the end of the campaign. This would enable instrument adjustments during the campaign. ARM recently learned that the internet connection in Hobart, Tasmania is good and ARM expects to transfer data after every leg straight to the ARM Data Center (ADC) without any shipment of disks.

3.0 Agenda

6th DOE ARM Radar Workshop

October 24-26, 2017

Day 1 Tuesday October 24, 2017

Time	Topic	Presenter
08:30 - 08:45	Introduction	Bharadwaj, Kollias
08:45 - 09:15	Radar Engineering and Operations Update	Bharadwaj
09:15 - 09:45	X-band Scanning ARM Precipitation Radar (XSAPR)	Lindenmaier
09:45 - 10:15	Eastern North Atlantic SACR & KAZR	Isom
10:15 - 10:30	--------------------------- Break ---------------------------	
10:30 - 11:00	AMF3 (Oliktok Point) SACR & KAZR	Hardin
11:00 - 11:20	Data QC	Isom
11:20 - 11:40	Data Flow	Hardin, Gaustad
11:40 – 12:00	Radar Data Processing	Records
12:00 - 13:00	--------------------------- Lunch ---------------------------	
13:00 - 13:20	Data Quality Office	Theisen
13:20 - 14:15	Strategic Plan for the Radars	Bharadwaj, Mather
14:15 - 14:45	Radar Plan	Bharadwaj
14:45 - 15:00	--------------------------- Break ---------------------------	
15:00 - 16:00	Radar Plan (contd..)	Bharadwaj
16:00 – 17:00	Review Milestones, Action Items for Radar Engineering	Hickmon, Bharadwaj

Day 2 Wednesday October 25, 2017

Time	Topic	Presenter
08:30 - 10:00	**Radar Science Review and Outlook:** Review last year, identify new radar science and applications and discuss our strategy for interfacing with the broader user community	Kollias, Clothiaux, Fridlind
10:00 - 10:10	--------------------------- Break ---------------------------	
10:10 - 11:45	**Simulators:** What kind of simulators ARM needs to develop and why? Discussion lead S. Xie and E. Clothiaux.	Discussion leads: Xie and Clothiaux. Short contributions (5 min): Oue, Lamer, Dolan
11:45 - 13:15	--------- Visit to Radar Facility & Lunch ---------------	
13:15 - 14:00	**Spaceborne Radars:** Present the comparison between the historic MMCR and KAZR record and CloudSat. Discuss the potential of using GPM in the future.	Kollias, Puigdomenech
14:00 - 14:45	**Radar Polarimetry:** Discussion on priorities, data quality issues and new scientific applications.	Kumjian, Oue
14:45 - 15:00	--------------------------- Break ---------------------------	
15:00 - 15:30	**Multi-wavelength**: Scientific applications of multi-wavelength radar observations and radar data quality requirements	Tridon
15:30 - 16:00	**Radar Doppler spectra:** MicroARSCL and spectra compression	Luke
16:00 – 17:30	**AMF/IOP Radar Data Product Needs:** MOSAIC, CACTI, MARCUS, LASIC, ENA and OLI: Short contributions on site and AMF deployment specific radar observations and radar data products	Varble (CACTI), Shupe (MOSAIC) Marchand (MARCUS), Miller (ENA), Maahn (OLI) and Zuidema (LASIC)

Day 3 Thursday October 26, 2017

Time	Topic	Presenter
08:30 - 09:15	Recap of Day 2	Clothiaux, Kollias
09:15 – 10:00	Needs from the modeling community (CMDV, ASR)	Zhe Feng, van Lier-Walqui
10:00 - 10:15	---------------------------- Break ----------------------------	
10:15 - 10:40	Needs from the modeling community (ACME)	S. Xie
10:40 – 12:00	ARM Radar Translators (FY-18 plans)	Giangrande, Collis
12:00 – 13:00	---------------------------- Lunch ----------------------------	
13:00 – 14:45	Prioritization of Radar Data Product Efforts	Comstock
14:45 - 15:00	---------------------------- Break ----------------------------	
15:00 – 16:00	Review Milestones, Action items	Comstock, Kollias

4.0 Participant List

Last Name	First Name
Bharadwaj	Nitin
Lindenmaier	Andrei
Isom	Bradley
Hardin	Joseph
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Mather	Jim
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Marchand	Roger

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Oue	Mariko
Borque	Paloma
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Tridon	Frederic
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