DOE/SC-ARM-TR-291

# ARM FY2024 Radar Plan


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# Acronyms and Abbreviations

| | |
|---|---|
| AMF | ARM Mobile Facility |
| AMS | American Meteorological Society |
| ANL | Argonne National Laboratory |
| ANX | Andenes, Norway |
| ARM | Atmospheric Radiation Measurement |
| ARMBE | ARM Best Estimate Value-Added Product |
| ARM-DIAGS | ARM Data-Oriented Metrics and Diagnostic Value-Added Product |
| ARMOR | Advanced Radar for Meteorological and Operational Research |
| ARSCL | Active Remote Sensing of Clouds Value-Added Product |
| ASR | Atmospheric System Research |
| BNF | Bankhead National Forest |
| BNL | Brookhaven National Laboratory |
| CACTI | Cloud, Aerosol, and Complex Terrain Interactions |
| CAPE-K | Cloud and Precipitation Experiment at Kennaook |
| CFAD | contoured frequency by altitude diagram |
| CLDPHASE | Cloud Phase Value-Added Product |
| CMAC | Corrected Moments in Antenna Coordinates Value-Added Product |
| COMBLE | Cold-Air Outbreaks in the Marine Boundary Layer |
| COURAGE | Coast-Urban-Rural Atmospheric Gradient Experiment |
| CSAPR2 | C-band Scanning ARM Precipitation Radar (2nd generation) |
| CSU | Colorado State University |
| DOE | U.S. Department of Energy |
| DQ | Data Quality |
| DQPR | Data Quality Problem Report |
| DQR | Data Quality Report |
| DSD | disdrometer |
| ENA | Eastern North Atlantic |
| EPC | EPCAPE |
| EPCAPE | Eastern Pacific Cloud Aerosol Precipitation Experiment |
| FTE | full-time equivalent |
| FY | fiscal year |
| GE | general mode |
| GUC | Gunnison, Colorado |
| HOU | Houston, Texas |
| HPC | high-performance computing |

| | |
|---|---|
| HSRHI | horizon-to-horizon range height indicator |
| IMB | Infrastructure Management Board |
| KASACR | Ka-band Scanning ARM Cloud Radar |
| KAZR | Ka-band ARM Zenith Radar |
| KAZR2 | Ka-band ARM Zenith Radar (2$^{nd}$ generation) |
| KCG | Kennaook/Cape Grim |
| KDP | specific differential phase |
| LANL | Los Alamos National Laboratory |
| LLNL | Lawrence Livermore National Laboratory |
| MD | moderate sensitivity mode |
| MICROBASE | Continuous Baseline Microphysical Retrieval Value-Added Product |
| MICROBASEKAPLUS | Improved MICROBASE Product with Uncertainties Value-Added Product |
| MOS | MOSAiC |
| MOSAiC | Multidisciplinary Drifting Observatory for the Study of Arctic Climate |
| MWACR | Marine W-band ARM Cloud Radar |
| MWR | microwave radiometer |
| NEXRAD | Next-Generation Weather Radar |
| NSA | North Slope of Alaska |
| PI | principal investigator |
| PNNL | Pacific Northwest National Laboratory |
| PPI | plan position indicator |
| Py-ART | Python ARM Radar Toolkit |
| QC | quality control |
| QPE | quantitative precipitation estimate |
| RadCLss | Extracted Radar Columns and In Situ Sensors Value-Added Product |
| RCA | radar calibration |
| RHI | range height indicator |
| RMBL | Rocky Mountain Biological Laboratory |
| SACR | Scanning ARM Cloud Radar |
| SAIL | Surface Atmosphere Integrated Field Laboratory |
| SGP | Southern Great Plains |
| SQUIRE | Surface Quantitative Precipitation Estimation Value-Added Product |
| TRACER | Tracking Aerosol Convection Interactions Experiment |
| TWT | traveling wave tube |
| UAH | University of Alabama, Huntsville |
| UTC | Coordinated Universal Time |
| VAP | value-added product |

| | |
|---|---|
| VPT | vertically pointing profile |
| WARNO | Watchdog for ARM Radar Network Operations |
| WSACR | W-band Scanning ARM Cloud Radar |
| XSAPR | X-band Scanning ARM Precipitation Radar |
| XSAPR2 | X-band Scanning ARM Precipitation Radar (2nd generation) |
| ZDR | differential reflectivity |

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# 1.0 Introduction

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility's radar capability aims to provide high-quality radar observations to the scientific community, advancing the understanding of clouds and precipitation processes and ultimately improving climate models. ARM operates radars across a spectrum of frequencies with diverse scanning capacities (Table 1) to meet these scientific goals. The maintenance, operations, and management of these distributed radars at sites in various climate regimes require a substantial staffing commitment. However, the existing staffing resources are constrained, making it impractical to sustain the consistent high-quality operations that are expected by the ARM user community. In response, ARM needs to develop priorities for the radar team each year. This report lays out the forthcoming priorities for Financial Year 2024 (FY24), aiming to establish a structure for the ongoing management of radar operations and data processing.

**Table 1**. Inventory of ARM radars, including hardware spec, at each site. Frequencies are approximate and can be slightly different in the field.

| Band | Name | Site | Frequency; Wavelength | Transmit Power | Antenna Diameter | Beam Width* | Typical Range Resolution | Polarization | Type |
|---|---|---|---|---|---|---|---|---|---|
| W-Band | **WSACR**<br>**WSACR2**** | SGP<br>AMF1<br>ENA<br>NSA | 93.9 GHz;<br>3.19 mm | 1.7 kW | 0.9 m | 0.33° | 30-150 m | Transmit horizontal linear<br>Dual | Scanning |
| W-Band | **MWACR** | AMF2 | 95 GHz;<br>3.15 mm | 1500 W | 3.0 m | -- | 30-150 m | Single | Zenith |
| Ka-Band | **KASACR**<br>**KASACR2**** | SGP<br>AMF1<br>AMF3<br>ENA<br>NSA | 35.3 GHz;<br>8.50 mm | 2.0 kW | 1.8 m | 0.33° | 30-150 m | Transmit horizontal linear<br>Dual | Scanning |
| Ka-Band | **KAZR**<br>**KAZR2**** | NSA<br>SGP<br>AMF1<br>AMF2<br>ENA<br>AMF3 | 34.0 GHz;<br>8.57 mm | 187 W<br>2.0 kW | 2.0 m<br>3.0 m (SGP) | 0.3°<br>0.2° (SGP) | 30-60 m | Single (AMF2)<br>Dual (SGP, NSA, AMF1, ENA, AMF3) | Zenith |
| X-Band | **XSACR** | AMF3 | 9.71 GHz;<br>3.09 cm | 20 kW | 1.8 m | 1.4° | 30-150 m | Dual | Scanning |
| X-Band | **XSAPR**<br>**XSAPR2** | NSA<br>SGP (I4, I5, I6)<br>ENA | 9.45 GHz;<br>3.17 cm | 200 kW<br>350 kW | 2.4 m<br>5.3 m | 1.0°<br>0.5° | 100 m | Dual | Scanning |
| C-Band | **CSAPR**<br>**CSAPR2** | SGP<br>AMF3 | 6.25 GHz;<br>4.80 cm<br>5.7 GHz;<br>5.26 cm | 350 kW | 4.3 m | 0.9° | 100 m | Dual | Scanning |

# 2.0 Fiscal Year 2023 Summary

During FY23, considerable effort was directed towards both primary and secondary undertakings. The primary activities included Ka-band ARM Zenith Radar (KAZR) operations; preparation, installation, and operations of the ARM Mobile Facilities (AMFs) for field campaigns; and b1 data analysis and processing of Cold-Air Outbreaks in the Marine Boundary Layer (COMBLE), Multidisciplinary Drifting

Observatory for the Study of Arctic Climate (MOSAIC), Tracking Aerosol Convection Interactions Experiment (TRACER), and Surface Atmosphere Integrated Field Laboratory (SAIL). Concurrently, secondary activities involved radar operation at fixed sites, accompanied by the processing of data quality and value-added products (VAPs). Table 2 summarized the FY23 radar operations. Radar operations generally met the FY23 plan, except for unexpected hardware malfunctions. Short-term data intermittence of hours to days are due to common factors of maintenance or environments, which are listed in the b1 data and data quality reports (DQRs).

**Table 2**. The FY23 radar operations plan at mobile (AMF) and permanent sites. AMFs were deployed in the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE), SAIL, and the southeast U.S. in Bankhead National Forest (BNF). Three fixed sites encompassed the Eastern North Atlantic (ENA), North Slope of Alaska (NSA), and Southern Great Plains (SGP).

| Site | AMF1 EPCAPE | AMF2 SAIL | AMF3 BNF | ENA | NSA | SGP |
|---|---|---|---|---|---|---|
| **Time** | 2023/02-2024/02 | 2021/09-2023/06 | 2023/09-2028 | All-year operations for KAZR. Scanning radar operations at ENA, SGP, and NSA are focused during spring and summer. | | |
| **FY23 Radar operations** | KAZR | KAZR | Preparation for: KAZR2 KASACR XSACR CSAPR2 | KAZR2 | KAZR | KAZR |
| | KASACR | Preparation for new site CAPE-K in 2024/04 | | KaSACR2 | KaSACR2 | XSAPR-I4 |
| | WSACR | | | WSACR2 | WSACR2 | XSAPR-I5 |
| | | | | XSAPR2 | XSAPR | XSAPR-I6 |

## 2.1 Primary Activities

### 2.1.1 KAZR Operations and Upgrades

The operational status of KAZRs across all sites remained consistently robust during FY23. To enhance radar capabilities, the engineering team undertook several upgrades, including implementation of dual polarizations for AMF-1 and AMF-2 KAZRs, replacement of hardware components such as traveling wave tube (TWT) power supplies, alteration of antenna radomes, and enhancements to signal processing to effectively mitigate sidelobe issues. Currently all operational KAZRs are dual-polarimetric. Occasional instances of brief downtime were attributed to factors such as power outages, snow removal from antenna surfaces, routine technician maintenance, and engineering upgrades. Moreover, the data team diligently ensured the continuity and stability of collected data. Figure 1 shows the pulse compression stability of KAZRs across the ARM fixed sites. Notably, the difference in reflectivity between general mode (GE) and moderate sensitivity mode (MD) generally consistently remains within 1 dB. A 3-dB reflectivity difference at ENA since late May 2023 was related to the filter change of signal processing.

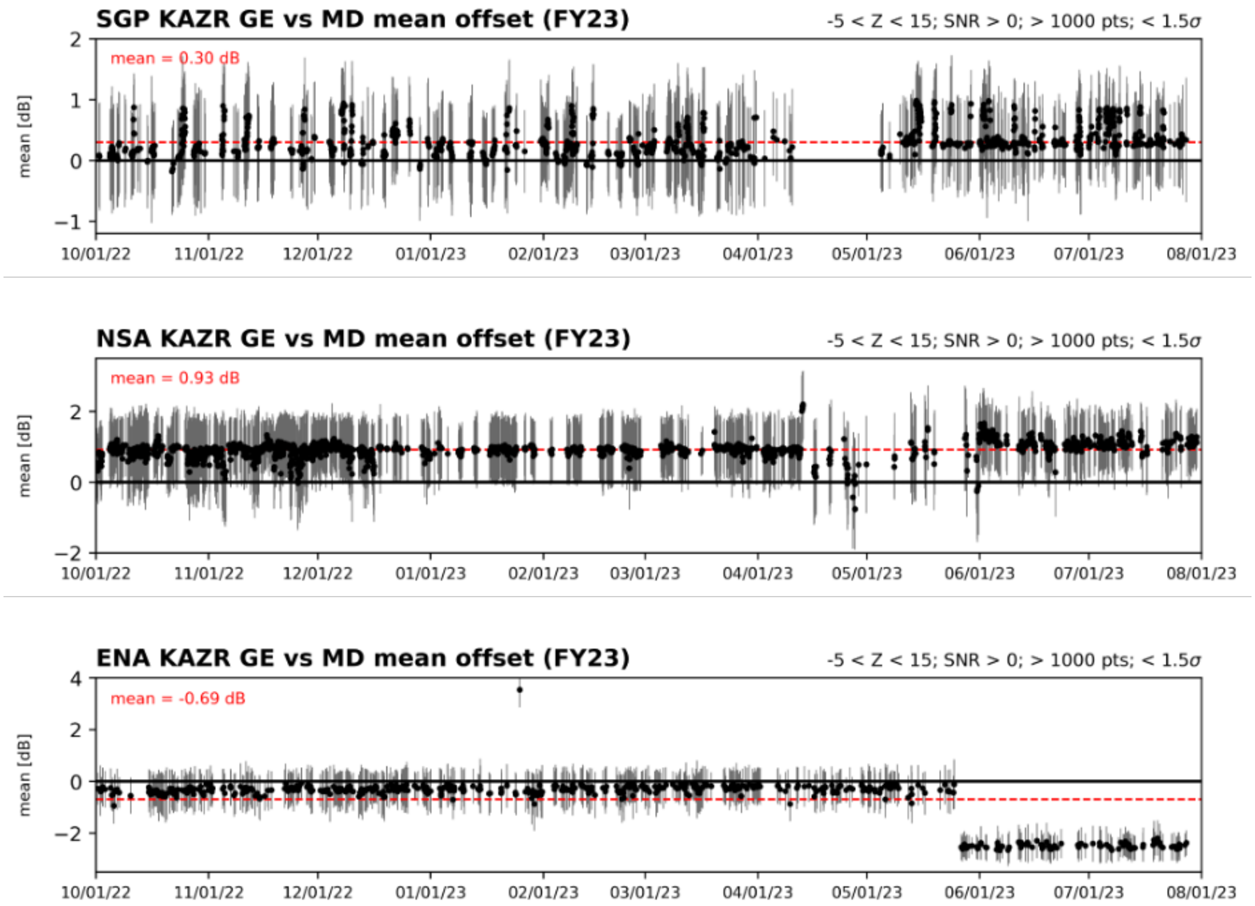


**Figure 1**. KAZR GE and MD mode difference for three fixed sites: SGP, NSA, and ENA during FY23.

### 2.1.2 Mobile Facilities

#### 2.1.2.1 SAIL

The SAIL campaign aims to measure the seasonally varying water budgets within the complex high-altitude terrain of Crested Butte, Colorado. The ARM KAZR was deployed for the SAIL campaign from September 2021 to June 2023. Colorado State University (CSU) was contracted to deploy their dual-polarimetric X-band radar on Crested Butte (GUC S2).

Throughout the campaign, the KAZR performed well and collected nearly full-time data. Some short downtime was experienced due to outages and snow removal from the antenna. The data quality of KAZR is stable during the experiment. Reflectivity measurements from the KAZR are consistent with those from the CSU X-band radar. The preliminary reflectivity comparison between the KAZR and CSU X-band radar, in conjunction with the disdrometer, revealed a small offset within 3 dB during summer months, while considering the effects of attenuations and of wet radome. The preliminary findings on data quality were actively shared and discussed in workshops and conferences involving stakeholders and users. The finalized b1-level calibrated data are expected to be released in the winter of FY24.

During SAIL the radar team worked on Corrected Moments in Antenna Coordinates (CMAC) and for the first time included estimates of snowfall rates using a range of simple reflectivity relations (Figure 2). By providing several estimates, this VAP communicates some of the uncertainties in the retrieval. CMAC is available for a subset of the SAIL campaign and the rest of the campaign, including rain events, will be made available in FY24.

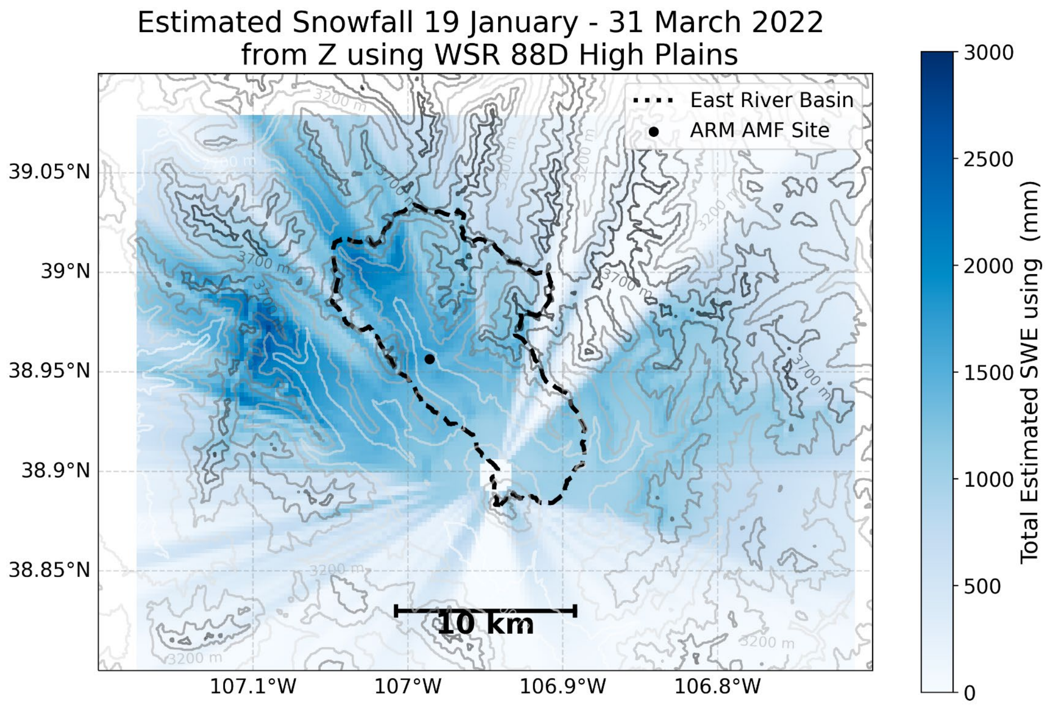


**Figure 2**. Example of estimated snowfall from the CMAC VAP at SAIL from January 19, 2022 to March 31, 2022.

Two new VAPs were developed specifically for SAIL: Surface Quantitative Precipitation Estimation (SQUIRE), which estimates snowfall rates at the surface by detecting beam blockage and finding the lowest possible gate for estimating surface rates (from CMAC), and the Extracted Radar Columns and In Situ Sensors (RadCLss) VAP, which extracts a matched column of radar data over in situ assets and creates a holistic view. The target audience for RadCLss is the retrieval community.

#### 2.1.2.2 EPCAPE (site code: EPC)

The AMF1 KAZR and Ka/WSACR were deployed in La Jolla, California from February 2023 to February 2024. KAZR and SACR data help acquire marine cloud properties within coastal cities, providing valuable opportunities to delve into cloud interactions with aerosols and radiative characteristics.

During the deployment phase, the scanning strategy was set up and tested to meet the science team's distinctive design, with a six-hours heartbeat cycle (see Appendix Table 6). Additionally, onsite calibrations were performed to ensure antenna pattern, pointing accuracy, and alignments. The data team analyzed local environment factors to ensure the stability of data quality, radar pointing, terrain blockages, and gas attenuation analysis. The limited coverage of the WSACR in comparison to the KASACR is due to water vapor attenuation.

While in operation, KAZR data collection is nearly continuous. Instances of missing data are due to occasional outages. The SACR demonstrated reliable operations with interruptions for hardware maintenance or critical weather conditions, including the replacement of a new RF system on Ka-side in March, the replacement of rotary joints due to leakage in July, and the effect of Storm Hilary.

#### 2.1.2.3 Southeast U.S. in Bankhead National Forest (BNF)

The forthcoming AMF3 deployment, including KAZR2, KA-XSACR, and CSAPR2, is set to take place in the Bankhead National Forest (BNF) in northwestern Alabama for a five-year duration. Originally, ARM targeted early September for installation, envisioning that the radar would be online and data collection would commence by the end of FY23. This timeline has been delayed due to several circumstances. Currently, the target for KAZR installation has been shifted to November 2023, followed by the installation of the CSAPR2 and SACR in spring 2024.

#### 2.1.2.4 Cloud and Precipitation Experiment at Kennaook (CAPE-K, site code: KCG)

The AMF-2 KAZR and Marine W-band ARM Cloud Radar (MWACR) will be installed in Tasmania, Australia from April 2024 to September 2025 to study the clouds over the Southern Ocean and improve cloud uncertainties in model simulations. Preparations for hardware calibrations, data ingest, and data evaluations were performed in August 2024 at Los Alamos National Laboratory (LANL) and Pacific Northwest National Laboratory (PNNL).

#### 2.1.2.5 Quality-Controlled Data (b1 Level)

To ensure the quality of radar data, both engineering and data teams oversee radar performance across various aspects, including hardware, software, signal processing, and data processing at different radar operation stages (Appendix Table 7). After the post-process of raw a1 data, the b1 radar data provides the quality control data, including bias corrections for reflectivity-related fields and data masking for quantitative applications (Figure 3). The b1 data can be downloaded from ARM's Data Discovery and the b1 report is presented on the ARM field experiment web page. In addition, real-time data issues, b1-level results, analysis, and methodology have been shared and discussed with stakeholders in meetings with principal investigators (PIs), ARM/Atmospheric System Research (ASR) meetings, and American Meteorological Society (AMS) conferences. The FY23 progress of b1 radar data products, including data and report is summarized in Table 3.

**Table 3.** The progress of b1 products (data and report) in FY23.

| Site (site code) | Time periods/location | Radar deployment | B1 data/report progress |
|---|---|---|---|
| COMBLE (ANX) | Dec 2019-June 2020<br>Andenes, Norway in the north Atlantic | Ka/WSACR<br>KAZR<br>(AMF1) | Released in Feb 2023.<br>(Matthews et al. 2023) |
| MOSAiC (MOS) | Oct 2019-Oct 2020<br>Ship borne, in the central Arctic Ocean ice environment | KAZR, MWACR<br>KASACR<br>(AMF2) | b1 products are expected to be released at the end of FY23. |
| TRACER (HOU) | Oct 2021-Sep 2022<br>Intensive IOP: June 2022-Sep 2022<br>Houston area, Texas, USA | KAZR,<br>Ka/XSACR<br>CSAPR2<br>(AMF1) | b1 products are expected to be released in the beginning of FY24. |
| SAIL (GUC) | Sep 2021-June 2023<br>Crested Butte, Colorado | KAZR | b1 products are expected to be released in early 2024. |

Scanning radar datastreams and filenames have had the scan types (plan position indicator [PPI], Horizon-to-horizon range height indicator [HSRHI], vertically pointing profile [VPT], etc.) removed for most operational radars since 2019. Some radars were brought back into operation in 2022, thus their file names were transitioned to scanless filename formats. For example, previous data file names contained the scanning modes (e.g., kasacr2cf2srhi, kasacrcfrvpt). Following the modification, the scanless filenames are standardized as “kasacr2cfr”, omitting the specific scanning strategy. The modification of the ARM SACRs at NSA and ENA filenames started from October 6, 2022; the modification of the SGP XSAPR ingest was from May 30, 2023. Users would expect different data filenames when requesting data in Data Discovery. For data user's interest and reference, Appendix A includes the scanning strategies of the operational ARM scanning radars in FY23.

## 2.2 Secondary Activities

### 2.2.1 ENA Radar Operations

Summer is the favored operational period at ENA for precipitation and mesoscale convection studies, aligning with scientific interests discussed during the ENA Radar Listening Session. Ka/WSACR2 had been actively in operation and collected data through FY23. XSAPR has been down due to transmitter issue and is not expecting any engineering or data efforts for operations due to limited human resources.

### 2.2.2 NSA Radar Operations

SACR2 had been operated since Aug 2022 after the engineer’s maintenance trip, and it was planned to operate for six months. However, the SACR2 went down in Dec 2022 due to frozen pedestal issues caused by cold weather. XSAPR started operation after transmitter replacement in October 2022 and has been providing valuable stable radar data.

### 2.2.3 SGP Radar Operations

XSAPRs at SGP were operational from May to July, targeting study of deep convection and storm life cycle. Local wind turbines have increased in number (Figure 3), interfering with radar signals and causing challenges on data quality. Identifying and mitigating the impact of wind turbines will be necessary in future b1 data processing. Due to the data collection period being shorter than three months, these issues will be documented in a DQR, but no b1 data processing will be conducted in FY23. An initial assessment of the data reveals that the data quality of XSAPRs at I4 is stable. XSAPR at I5 exhibited some issues with dual-polarimetric data. The XSAPR located at I6 had a remote-control problem towards the end of the testing period and was shipped to PNNL for maintenance.

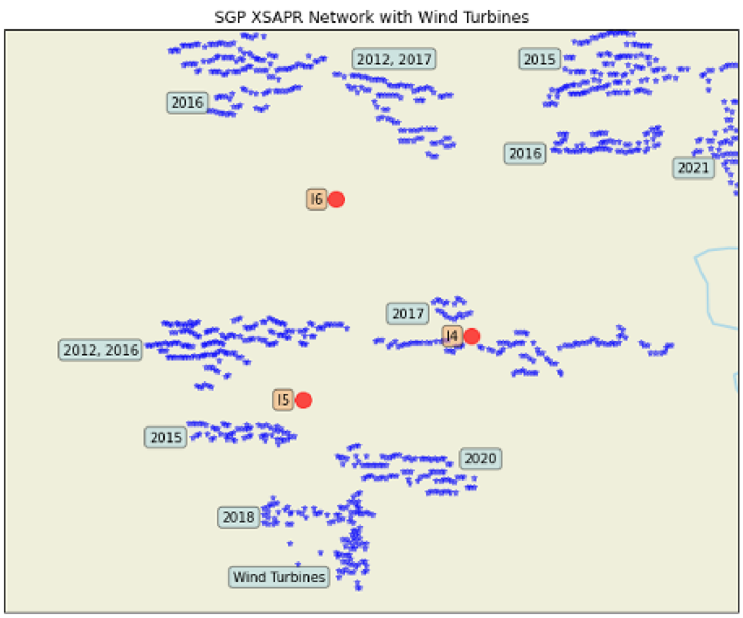


**Figure 3**. The XSAPRs and the wind farm at the SGP site. XSAPRs including: XSAPR-SE (I4), XSAPR-SW (I5), and XSAPR-NW (I6) are shown in red dots. The wind farms that have been expanding in recent years are shown as blue dots. Wind turbines information can be obtained here: https://eerscmap.usgs.gov/uswtdb/viewer/#3/37.25/-96.25 (Hoen et al. 2018).

# 3.0 Fiscal Year 2024 Priorities

The radar plan for FY24 outlines a comprehensive plan comprising activity, priorities, and a projected timeline in accordance with the radar roadmap. The generic tasks encompass radar installation, radar operations, real-time data monitoring, a1-to-b1 data processing, and radar maintenance. Coordination of these endeavors is overseen by both engineering and data teams, ensuring smooth operation and data quality across various stages of deployment.

- Radar Preparation and Installation – This phase involves radar hardware calibration and examinations, shipping of instruments, establishment of data ingest workflow, and installation process for new sites.
- Radar Operations – The engineering team takes charge of routine maintenance, troubleshooting, and repairs, calibrations, and training of site technicians.

- Radar Data Monitoring – The data team is responsible for routine monitoring of data collection, ingest, qualitatively stability assessment, troubleshooting and updates, and data quality initiatives (Data Quality Problem Report [DQPR]/DQR).
- a1-to-b1 Data Analysis and Processing – Following the standard ARM data quality process, this step entails providing data corrections and uncertainty analysis for b1-level data through data-based calibrations, cross-comparisons, configuration generation, and generation of comprehensive reports.
- Radar Maintenance and Testing – Efforts are dedicated to bringing the radar(s) back online and monitoring them from a hardware perspective to ensure smooth operations.

Detailed FY24 activities are summarized in Table 4, including new and ongoing activities. Figure 4 provides a Gantt chart of these activities. As of the present, the estimated full-time equivalents (FTEs) for the radar engineering and data team are 5.9 and 3.75. respectively. The ARM Infrastructure Management Board (IMB) has proposed certain alterations concerning operational and retiring radars, considering budget and staffing. Table 5 summarized the FY24 radar operations. In contrast to previous plans, time for conferences, meetings, and unexpected tasks (repairs, user questions, large problems, etc.) is being allocated to ensure a more realistic view of effort allocations.

**Table 4**. Activities planned for FY24 Radar Team. Engineering-related tasks are highlighted in gray, data-related tasks in blue.

| No. | Activity | Start date | End date | Staffing | Priority | Planned FTE |
|---|---|---|---|---|---|---|
| 1 | **KAZR operations** (NSA, ENA, SGP, EPC, KCG, BNF) | 10/1/2023 | 9/30/2024 | Wendler, Lindenmaier, Castro, Argay, Houchens, Breedlove, Androes | Primary | 1.6 |
| 2 | KAZR data monitoring and operations (NSA, ENA, SGP, EPC, KCG, BNF) | 10/1/2023 | 9/30/2024 | Deng, Feng, Matthews, Schuman, Rocque | Primary | 0.45 |
| 3 | KAZR b1 data processing (SGP, ENA, NSA) | 10/1/2023 | 9/30/2024 | Feng, Matthews, Deng, Schuman, Rocque | Primary | 0.6 |
| 4 | **SAIL b1 data analysis and processing** | 10/1/2023 | 12/31/2023 | Matthews, Deng, Schuman, Feng | Primary | 0.15 |
| 5 | **EPCAPE radar operations** (SACR) | 2/15/2023 | 2/14/2024 | Lindenmaier, Wendler, Argay | Primary | 0.4 |
| 6 | EPC data monitoring and operations (SACR) | 2/15/2023 | 2/14/2024 | Feng, Rocque, Matthews | Primary | 0.1 |
| 7 | EPC b1 data processing (SACR, KAZR) | 1/1/2024 | 8/31/2024 | Rocque, Deng, Feng, Matthews | Primary | 0.65 |
| 8 | **BNF Radar operations** | 12/15/202 | Onward | Lindenmaier, Wendler, Castro, | Primary | 0.4 |

| No. | Activity | Start date | End date | Staffing | Priority | Planned FTE |
|---|---|---|---|---|---|---|
| | (SACR, CSAPR operation by Baron) | 3 | | Houchens, Hutchinson | | |
| 9 | BNF radar installation (KAZR) | 12/15/2023 | 02/15/2024 | Lindenmaier, Wendler, Castro | Primary | 0.1 |
| 10 | BNF radar installation (CSAPR2) | 5/1/2024 | 6/30/2024 | Lindenmaier, Wendler, Castro | Primary | 0.2 |
| 11 | BNF radar installation (SACR) | 5/1/2024 | 6/30/2024 | Lindenmaier, Wendler, Castro | Secondary | 0.2 |
| 12 | BNF data monitoring and operations (CSAPR2, SACR) | 6/1/2024 | Onward | Rocque, Matthews, Feng, Schuman | Primary | 0.45 |
| 13 | BNF b1 data analysis and evaluation (KAZR, SACR and, CSAPR2 3-months) | 6/1/2024 | 9/30/2024 | Rocque, Matthews, Feng, Schuman | Primary | 0.2 |
| 14 | **CAPE-K radar operations (MWACR)** | 2/1/2024 | Onward | Lindenmaier, Wendler, Castro | Primary | 0.2 |
| 15 | KCG radar installation | 2/1/2024 | 4/30/2024 | Lindenmaier, Wendler, Castro | Primary | 0.05 |
| 16 | KCG data monitoring and operations (MWACR) | 3/1/2024 | Onward | Matthews, Feng, Rocque | Primary | 0.1 |
| 17 | **AMF CoURAGE urban preparations for FY25 - KAZR** | 7/1/2024 | 9/31/2024 | Lindenmaier, Wendler, Castro, Schuman | Primary | 0.15 |
| 18 | **Deployable CSAPR procurement** | 11/1/2023 | 4/30/2024 | Lindenmaier, Wendler, Castro, Flaherty, Feng | Primary | 0.25 |
| 19 | **Automatic data quality monitoring system and handbooks updates** | 10/1/2023 | 07/31/2024 | Feng, Schuman, Rocque, Matthews, Deng | Primary | 0.25 |
| 20 | **Metadata on cell tracking statistics (cell id, tracks)** | 10/1/2023 | 1/31/2024 | Gupta | Primary | 0.2 |
| 21 | **NSA radar operations** (XSAPR) | 3/1/2023 | 5/31/2024 | Lindenmaier, Houchens | Secondary | 0.1 |
| 22 | NSA data monitoring and operations | 3/1/2023 | 5/31/2024 | Feng, Rocque, Matthews, Schuman | Secondary | 0.05 |

| No. | Activity | Start date | End date | Staffing | Priority | Planned FTE |
|---|---|---|---|---|---|---|
| 23 | NSA XSAPR b1 data analysis and processing (3 months) | 5/1/2024 | 8/31/2024 | Feng, Rocque, Matthews, Schuman | Secondary | 0.2 |
| 24 | **ENA b1 data analysis** (SACR for FY22) | 10/1/2023 | 9/31/2024 | Feng, Matthews, Schuman, Rocque | Secondary | 0.35 |
| 25 | **NSA SACR2 maintenances, repairs, and upgrades** | 1/1/2024 | 08/31/2024 | Lindenmaier, Wendler, Castro | Secondary | 1.5 |
| 26 | **SGP XSAPR I6 maintenance; CSAPR, XSAPR -I4 andI5, SACR removed** | 10/1/2023 | 9/30/2024 | Lindenmaier, Wendler, Castro | Secondary | 0.2 |
| **27** | **Meetings, conferences, plan discussion, unanticipated repairs** | 10/1/2023 | 9/30/2024 | Engineer and Data teams | | 0.55 (E)<br>0.2 (D) |
| | Total FTE | | | | | 9.65 |
| | Data Mentor FTE | | | | | 3.75 |
| | Engineering Mentor FTE | | | | | 5.9 |
| | Translator FTE | | | | | |

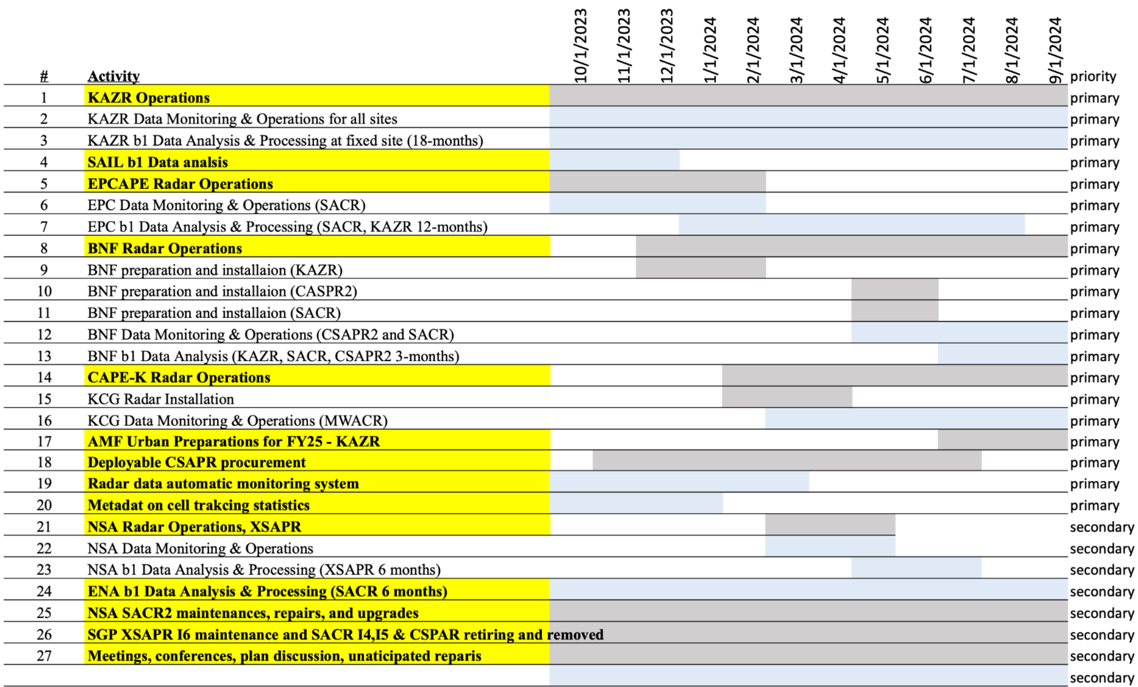


**Figure 4**. Gantt chart of activities. Color-coded by engineering (gray) and data (blue).

**Table 5**. List of operational and maintenance radars during FY24.

| Site | AMF1 EPCAPE | AMF2 CAPE-k | AMF3 BNF | ENA | NSA | SGP |
|---|---|---|---|---|---|---|
| **Time** | **2023-02-15 2024-02-14** | **2024-04** | **2024-01** | **All year** | **All year** | **All year** |
| **FY24 operations** | KAZR | KAZR | KAZR2 | KAZR2 | KAZR | KAZR |
| | KaSACR | MWACR | KaSACR | | XSAPR (spring) | |
| | WSACR | | XSACR | | | |
| | | | CSAPR2 | | | |
| **FY24 maintenance** | at SGP: XSAPR-I6<br>at PNNL: NSA Ka/WSACR | | | | | |

## 3.1 Primary Activities

### 3.1.1 KAZR Operations

Task no: 1,2,3 FTE: 2.65 10/1/2023-12/31/2023

Staffing: Wendler, Lindenmaier, Castro, Argay, Houchens, Breedlove, Androes, Feng, Matthews, Deng, Rocque, Schuman

The KAZRs have the most extensive long-term users and maintain a high priority across all ARM fixed sites and AMF deployments. Radar engineers and technicians will conduct routine calibration, maintenance, and repairs as needed, ensuring the stability of radar hardware systems and maintaining the quality of signal processing.

The radar data team is responsible for monitoring operational radar data sets. Processing KAZR data from a1 to b1 level is a top priority for the radar data team, spanning all sites, including both mobile and fixed facilities. The b1 data processing of SGP and ENA KAZR will be prioritized, given the methodology's compatibility and the availability of surrounding radars or instruments for intercomparison.

**Tasks**

- KAZR operations/routine maintenance/repairs for all sites: 1.6 FTE
- KAZR data monitoring and operations for all sites: 0.45 FTE
- KAZR b1 data processing at fixed site 2022/10-2024/03: 0.6 FTE

### 3.1.2 SAIL bi Processing and Report

Task no: 4 FTE: .15 10/1/2023-12/31/2023

Staffing: Feng, Matthews, Deng, Rocque, Schuman

The ARM KAZR was in operation during the SAIL campaign from September 2021 to June 2023. Initial assessment in FY23 indicates stable data quality for the KAZR, with comparisons with the CSU X-band radar and disdrometers. The systematic reflectivity offset of KAZR and the non-meteorological masks throughout the entire SAIL field campaign will be concluded in FY24. The release of b1-level calibrated data accompanying the data analysis report is anticipated by the end 2023.

**Tasks**

- SAIL b1 data analysis and processing (KAZR only): 0.15 FTE

### 3.1.3 EPCAPE Operations and b1 Data Analysis

Task no: 5,6,7 FTE: 1.15 10/1/2023-7/31/2024

Staffing: Lindenmaier, Wendler, Castro, Argay, Feng, Matthews, Deng, Rocque, Schuman

The AMF1 KAZR and Ka/WSACR have been deployed in California since February 2023. Radar operations and data quality monitoring will persist until February 2024. Following the campaign, the data team will process the b1-level data and with the b1 analysis report anticipated for delivery by July 2024.

**Tasks**

- EPCAPE radar operations: 0.4 FTE
- EPCAPE data monitoring and operations (SACR): 0.1 FTE
- EPCAPE b1 data analysis and processing (SACR, KAZR) 0.65 FTE

### 3.1.4 BNF (AMF#) Campaign Preparations, Installations, and Operations

Task no: 8,9,10,11,12,13 FTE: 1.55 10/1/2023-onward

Mentor staffing: Lindenmaier, Wendler, Castro, Houchens, Feng, Matthews, Deng, Rocque, Schuman

The AMF3 is set to undergo a five-year deployment within the BNF in northern Alabama. Throughout FY23, radar engineers and technicians have been preparing for operations in BNF.

During FY24, a series of installations are planned. KAZR2 is scheduled for installation at the main site around December 2023. Subsequently, CSAPR2 and Ka/XSACR installations are expected to occur in May 2024. The total duration of data collection is estimated to be a maximum of six months, contingent upon the installation timeline.

**Tasks**

- BNF radar operations: 0.4 FTE
- BNF radar preparations and installation (KAZR): 0.1 FTE
- BNF radar preparations and installation (CSAPR2): 0.2 FTE
- BNF radar preparations and installation (SACR): 0.2 FTE
- BNF data monitoring and operations (CSAPR2 and SACR): 0.45 FTE
- BNF b1 data analysis (KAZR, SACR, CSARP2 for 3 months): 0.2 FTE

### 3.1.5 CAPE-K Radar Operations

Task no: 14,15,16 FTE: .35 11/1/2023-onward

Mentor staffing: Lindenmaier, Wendler, Castro, Houchens, Feng, Matthews, Deng, Rocque, Schuman

The AMF-2 KAZR and MWACR will be installed in Tasmania, Australia from April 2024 to September 2025. Preparation, encompassing hardware calibration, data ingest setup, and preliminary data evaluation, has been underway since later FY23. In FY24, efforts will go into installation and operations, accompanied by real-time data collection and data quality monitoring.

**Tasks**

- KCG radar installation: 0.05 FTE
- KCG radar operations: 0.2 FTE
- KCG data monitoring and operations (MWACR): 0.1 FTE

### 3.1.6 AMF Radar Preparations for FY25 – COURAGE (Dec 1, 2024-Dec 1, 2025)

Task no: 17 FTE: .15 7/1/2024-onward

Mentor staffing: Lindenmaier, Wendler, Castro, Feng, Schuman

An AMF KAZR will be slated for Baltimore, Maryland, with the goal of investigating cloud properties in the urban environment during COURAGE. Radar preparations are projected to begin during the final months of FY24.

### 3.1.7 Deployable CSAPR Procurement

Task no: 18 FTE: .25 10/1/2023-9/31/2024

Mentor staffing: Lindenmaier, Wendler, Castro, Theisen, Feng, Flaherty, and other review committee

The C-band scanning precipitation radar is a powerful instrument for probing precipitation systems. The ARM CSAPR2, previously deployed in Cloud, Aerosol, and Complex Terrain Interactions (CACTI) and TRACER, is scheduled for installation at the AMF3 BNF site for a five-year deployment. Because CSAPR2 will not be available for deployment with other AMFs in the foreseeable future, ARM needs to procure an additional CSAPR2 unit for forthcoming mobile deployments or for SGP. A preliminary deployment site is anticipated to be the former CSAPR1 location at SGP, with the definitive selection to be confirmed.

### 3.1.8 Radar Data Automatic Monitoring System and Radar Data Handbook

Task no: 19 FTE: .25 10/1/2023-9/30/2024

Mentor staffing: Feng, Schuman, Rocque, Matthews

The data team oversees radar collection and evaluates the data quantitatively and qualitatively to assess data stability. In FY24, alongside regular data quality checks, the data team plans to present a real-time quantitative automated data quality monitoring system for ARM radars at various sites. The display will encompass elements like sky noises, hardware parameters, reflectivity difference between different modes, Radar Calibration (RCA) with ground clutters, and differential reflectivity (ZDR) bias estimates etc., based on the accumulated experiences gained in b1 processing, with support from the ARM Data Quality (DQ) Office and other members of ARM’s infrastructure. Automatic radar data quality monitoring display will be developed for each operational site. In addition, based on the interests and needs of data users, related radar data information will be updated in the handbooks.

### 3.1.9 Metadata on Cell Tracking Statistics

Task no: 20 FTE: .2 10/1/2023-11/30/2024

Mentor staffing: Gupta

To enhance the effective use of specific radar data collection, such as cell tracking scans during TRACER, it is important to establish metadata documentation and conduct statistical cell tracking analysis. Several ideas and thoughts have been discussed by science stakeholders. In response, we will initiate a call to gather input and feedback on these ideas. Subsequently, a collaborative effort between ARM and the broader scientific community will address metadata requirements and ensure their successful implementation.

## 3.2 Secondary Activities

These FY24 activities are subject to potential reevaluation should any existing primary tasks demand increased effort. Furthermore, the introduction of new primary activities will necessitate a review, prompting adjustment to secondary tasks as deemed necessary.

### 3.2.1 NSA Radar Operations

Task no: 21,22,23 FTE: .35 3/1/2023-8/1/2024

Mentor staffing: Wendler, Houchens, Lindenmaier, Feng, Matthews, Rocque, Schuman

NSA XSAPR will be operated during the spring of 2024. The XSAPR will temporarily transition into maintenance mode due to network instability for data transfer in early FY24. The radar will resume operation once the network stabilizes to ensure smooth data collection. Ka/WSACR has been sent back to PNNL in 2023, and is planned to be repaired and reinstalled in the FY24 summer.

**Tasks**

- NSA radar operations (6 months operations): 0.1 FTE
- NSA data monitoring and operations (6 months data monitoring): 0.05 FTE
- NSA b1 data analysis and processing (6 months of data): 0.2 FTE

### 3.2.2 ENA SACR b1 Processing

Task no: 24 FTE: .35 10/1/2023-9/31/2024

Mentor staffing: Feng, Matthews, Rocque, Schuman

Following discussions at the ENA Radar Listening Session, our primary focus will be analyzing and processing b1 data during summer and winter in FY23. The ENA SACR2 will not be operational in FY24, in accordance with a management decision. Nevertheless, the potential for its operation is under consideration for FY25 or beyond. Additionally, a plan for upgrade of the XSAPR will be developed in FY24.

**Tasks**

- ENA SACR b1 data analysis and processing (6 months of data): 0.35 FTE

### 3.2.3 NSA SACR2 Maintenance, Repairs, and Upgrades

Task no: 25 FTE: 1.5 10/1/2023-9/30/2024

Mentor staffing: Lindenmaier, Wendler, Castro, Chris, Brandom, Todd, Pete

The engineering team plans to work on hardware repair and maintenance on NSA SACR2. Currently, the radar is transferred back to PNNL for further work.

**Tasks**

- NSA SACR2 maintenance, repairs, and upgrades: 1.5 FTE

#### 3.2.4 SGP Precipitation Radars Maintenance and Removals

Task no: 26,27,28 FTE: .2 10/1/2023-9/30/2024

Mentor staffing: Lindenmaier, Breedlove, Androes, Feng, Matthews, Schuman, Rocque

ARM has decided to retire the XSAPRs at I4 and I5 as well as the CSAPR at I7. The plan entails two main efforts: 1) repairing the XSAPR-I6 issue mentioned in FY23 progress, and 2) removal and assessment of the CSAPR and XSAPRs at I4 and I5.

**Tasks**

- SGP XSAPR-I6 maintenance and return to operations; CSAPR2, XSAPR I4, I5, and SACR retiring and removal: 0.2 FTE

### 3.3 Translator and Data Product Activities

#### 3.3.1 Radar Data Analysis

Timeframe: FY24

Staff: Israel Silber, Jing Tian, and Sid Gupta

Four data analysts were hired in FY23 and will work on a variety of applications for ARM. A subset of these tasks will include characterization of ARM radar data and new radar-based products. Activities include the development of an ice precipitation product below cloud base (Silber), scanning radar statistics and spatial analysis during COMBLE (Silber), development of data epochs at ENA focused on open and closed cell structures (Tian), and cell tracking and identification at TRACER (Gupta).

#### 3.3.2 Radar Open Science Support

Timeframe: Ongoing

Staff: Sherman, Grover, Jackson, Collis

ARM will continue to  support the Python ARM Radar Toolkit (Py-ART), a very popular community codebase for working with radars. In FY20 Py-ART closed out its five-year roadmap, a year earlier than planned. In FY21 a new roadmap was written and reviewed. Item 1 covers the implementation of a subset of the Roadmap recommendations. For Py-ART support we will perform the following tasks, requiring 0.39 FTE:

- Routine maintenance of Py-ART, education, and outreach
- Answering, in a triaged manner with priority given to ARM stakeholders, user queries

- Delivering short courses at society meetings and DOE workshops
- Reporting back to ARM and providing details to the program to continue to justify investment.

The deliverables from this set of tasks will be a report at the end of the FY on achievements, a series of software updates to keep Py-ART current, and a series of software packages (mainly cmweather where we have put our colorblind friendly colormaps and xradar, which is a new international collaboration on ingests).

In addition, the group will create improvements that align with the Py-ART roadmap, requiring 0.43 FTE:

- We will have a xradar object using Python's xarray engine. FY24 work will focus on leveraging xarray's indexing and connections to Dask (HPC) for performance improvements.
- We will also continue to produce cookbooks to grow the Py-ART user base as users transitioning to contributors benefit ARM.

The deliverables from this task will be new software in Py-ART that uses xarray. This will include (but not be limited to) plotting, gridding, and using Dask to accelerate existing Py-ART functionality.

### 3.3.3 Precipitation Radar Advanced Products

Timeframe: Ongoing

Staff: Jackson, Sherman, Grover, O'Brien, Collis, Raut

ARM will continue processing b-level CSAPR2 data with Corrected Moments in Antenna Coordinates (CMAC). CMAC has already been produced for C-SAPR2. FY24 will see the delivery of CMAC based on b-level products from the TRACER CSAPR2. This involves the following tasks, requiring an estimated 0.34 FTE:

- Comparison between CMAC products and nearby NEXRAD to ensure the VAP is functioning as expected
- QC checks on the data including looking at ZDR in light rain to ensure corrections are working
- Produce an overview report on completion of the work
- Create a cookbook applying retrievals to CMAC including established particle ID code in Py-ART and Py-ART-related codebases including CSU radar tools.

In addition, ARM will ramp up and support initial CSAPR operations in Alabama in support of AMF3 to jumpstart science efforts. This will first involve some pre-deployment analysis of the disdrometer data and other DSD-relevant data. On deployment of the radar, the translator team will repeat work performed at TRACER, assisting the radar data engineers with code and support. This includes keeping a log of events, performing comparisons with NEXRAD and, when available, Advanced Radar for Meteorological and Operational Research (ARMOR) (University of Alabama, Huntsville [UAH]) reflectivity factor using code developed for TRACER. This is particularly relevant given the number of third-party radars in the area. As a-level data flows the team will begin workflow engineering for CMAC and, if there are no delays, have a small subset of direct a-c level data submitted for evaluation. The team will work very closely with the data engineering team so knowledge flows without barriers. We will document this in an end-of-year report. We estimate this will require 0.51 FTE.

Finally, ARM will complete the SAIL VAPS. Having delivered CMAC, SQUIRE, and RadCLss for SAIL for winter events, the team will complete rainfall retrievals and conduct rudimentary performance evaluation. Note: The “Shoulder” season where mixed phase is possible will be excluded. While all care will be taken, some mixed-phase precipitation will be included but the definitive identification of these events is out of scope and requires significant effort. This involves the following tasks:

- Apply identified specific differential phase (KDP) estimation algorithm to SAIL xprecipradar (Giangrande)
- Produce CMAC. A SQUIRE-like product for liquid precipitation is out of scope for FY24. Liquid quantitative precipitation estimate (QPE) will be provided as part of CMAC; however, the team will rely on the science community for the science needed for new relations at 10,000 feet+. The final task is a quick assessment of the skill of the snow retrievals. We will rely on the Pluvio rain gauge and measurements of snowpack by the Rocky Mountain Biological Laboratory (RMBL) team.

We estimate that this effort will require 0.42 FTE.

### 3.3.4 Cloud Radar and Adjacent Translator Advanced Products

Timeframe: Ongoing

Staff: Translator teams at Brookhaven National Laboratory (BNL), LLNL, and PNNL (Giangrande, Xie, Zhang)

As discussed in their recent FY23-25 Translator Plan, several ongoing and planned VAP and analysis tools from the translator group will make ARM cloud radar measurements more accessible to the community. Many of these product designs necessitate calibrated (typically, to within 2-3 dBz) and/or conditioned radar data sets as input, though several existing VAPs are robust to modest calibration offsets and/or can be run in ‘.c0’ (non-calibrated) variations to provide users with subsets of important geophysical quantities in a timely manner. Below is a listing of related VAPs for FY24 specific to the ARM cloud radars:

- The Active Remote Sensing of Clouds (ARSCL) VAP is a multisensor VAP that relies heavily on KAZR data for cloud designation. This VAP is typically available within a month of KAZR data collection. ARSCL also serves as input to several other VAPs, including the ARM Best Estimate (ARMBE) VAP and many VAPs discussed below.
- A Continuous Baseline Microphysical Retrieval product (MICROBASE, as well as Improved MICROBASE Product with Uncertainties [MICROBASEKAPLUS]) that provides liquid/ice water content and liquid/ice effective radius estimates with uncertainties (perturbation analysis). This VAP is multisensor (microwave radiometer [MWR] and KAZR, typically), and is unaffected by radar calibration offsets if applied in liquid media settings.
- A new Cloud Phase (CLDPHASE) VAP that provides vertically resolved cloud hydrometeor phase, as well as cloud layer thermodynamic phase classifications. This VAP is performed using combined lidar, radar, and radiometer measurements.

- ARM radar Contoured Frequency by Altitude Diagram (CFAD) data product based on KAZR/ARSCL to couple with models having forward radar simulators. These uses include the ARM data-oriented metrics and diagnostic package (ARM-DIAGS) developed by the translators for the global climate community.
- Availability of gridded, calibrated SACR data sets (SACRGRIDPPI/SACRGRIDRHI) to include TRACER, EPCAPE, and other SACR deployments at fixed sites.

# 4.0 Fiscal Year 2024 Communication Plan

Effective communication is important to convey ARM's radar plans, expectations, and outcomes regarding its radar initiatives. Communication is essential for both internal and external stakeholders, covering a spectrum of activities from engineering and data mentorship to translation efforts. ARM will focus on a variety of areas to enhance communications internally and with data users.

## 4.1 Internal

Radar mentors have a weekly call with site operations to exchange timely information about radar operations, needs, and follow-ups. Additionally, the radar mentors provide weekly updates on the ARM Operations call about radar engineering and data activities. While there are intermittent meetings and communications with various other groups in ARM (translators, developers, DQ Office, etc.) there will be an effort to coordinate quarterly calls with the larger radar ARM infrastructure group to discuss radar-related topics.

## 4.2 External

In FY23, the primary means of interaction between data users and ARM include email discussions, online meetings, and conferences. Most users are accustomed to inquiring radar operation status and data quality through radar mentors' emails or by using the Data Question bottom on the ARM website. Mentors promptly respond to these emails and, if necessary, arrange online meetings for further discussion. Data quality analysis had been presented during the ASR meeting and shared at conferences with scientists and potential users.

ARM holds monthly data user interaction calls, although user engagement in these calls has been limited. Additionally, ARM maintains a discourse page with radar topics (https://discourse.arm.gov/), which, to date, has not seen substantial engagement from data users. The radar.arm.gov website also houses routine radar information but has had reliability issues. To better engage with data users, ARM mentors will initiate more discussions with stakeholders on the monthly call and in the discourse forum. Special topics will be discussed on the calls every quarter which may include radar operations, interesting case studies, data quality, and more.

While in the FY23 plan the review of Watchdog for ARM Radar Network Operations (WARNO) and the radar.arm.gov website was not performed, it will be prioritized for FY24 to ensure that ARM has an easy and effective means of communicating radar status to the user community. Additionally, radar mentors will also update radar handbooks to include the latest information on first- and second-generation radar systems. ARM will also publish data announcements for b-level and VAP data releases and the mentor team will review the possibility of a quarterly blog post on radar activities.

# 5.0 References

Hoen, BD, JE Diffendorfer, JT Rand, LA Kramer, CP Garrity, and HE Hunt. 2018. United States Wind Turbine Database. U.S. Geological Survey, American Clean Power Association, and Lawrence Berkeley National Laboratory data release: USWTDB V1.2 (October 1, 2018). https://eerscmap.usgs.gov/uswtdb

# Appendix A

# Scanning Strategy and Quality Control

**Table 6**. Scanning strategy of the ARM scanning radars operated in FY23.

| Site | Radar | Heartbeat (min) | Scan type (# sweeps) | Length (min) | Azimuths (degree) | Elevations (degree) |
|---|---|---|---|---|---|---|
| **ENA** | **SACR2** | 10 | HSRHI (7) | 4 | 270, 300, 330, 0, 30, 60, 90 | 0-180 |
| | | | PPI (3) | 4 | 0-360 | 1.0, 2.0, 5.0 |
| | | | VPT | 2 | | 90 |
| **NSA** | **SACR2** | 10 | HSRHI (4) | 4 min | 52, 97, 142, 187 | 0-180 |
| | | | PPI (3) | 4 min | 0-360 | 0.5, 1.5, 3.0 |
| | | | VPT | 2 min | | 90 |
| | **XSAPR** | 15 | HSRHI (4) | 5 min | 52, 97, 142, 187 | 0-180 |
| | | | PPI (3) | 2 min | 0-360 | -0.5, 0.0, 1.0 |
| | | | PPI (6) | 4 min | 0-360 | 4.0, 5.0, 7.0, 10.0, 15.0, 20.0 |
| | | | VPT | 4 min | | 90 |
| **SGP** | **XSAPR (I4)** | 10 | PPI (18) | 6 min | 0-360 | 0.4, 1.1, 1.9, 2.6, 3.5, 4.4, 5.2, 6.4, 7.9, 9.5, 11.6, 14.3, 17.5, 21.4, 26.1, 33.0, 42.0, 50.0 |
| | | | RHI (6) | 2 min | 204.5, 245.1, 285.5, 292.6, 322.2, 351.5 | 0.5-90 |
| | | | VPT | 2 min | | 90 |
| | **XSAPR (I5)** | 10 | PPI (18) | 6 min | 0-360 | 0.4, 1.1, 1.9, 2.6, 3.5, 4.4, 5.2, 6.4, 7.9, 9.5, 11.6, 14.3, 17.5, 21.4, 26.1, 33.0, 42.0, 50.0 |
| | | | RHI (6) | 2 min | 7.6, 37.1, 37.6, 64.9, 95.8, 350.9 | 0.5-90 |
| | | | VPT | 2 min | | 90 |
| | **XSAPR (I6)** | 10 | PPI (18) | 6 min | 0-360 | 0.4, 1.1, 1.9, 2.6, 3.5, 4.4, 5.2, 6.4, 7.9, 9.5, 11.6, 14.3, 17.5, 21.4, 26.1, 33.0, 42.0, 50.0 |
| | | | RHI (6) | 2 min | 114.1, 142.0, 161.0, 163.3, 187.8, 211.4 | 0.5-90 |
| | | | VPT | 2 min | | 90 |

| Site | Radar | Heartbeat (min) | Scan type (# sweeps) | Length (min) | Azimuths (degree) | Elevations (degree) |
|---|---|---|---|---|---|---|
| **AMF 1** | **SACR** | 2 | PPI (7) | 2 min | 280-360 | 0.0, 2.5, 5.0, 7.5, 10.0, 15.0, 20.0 continuous unless performing second scan strategy (below) |
| **(EPCAPE)** | | ~34 | 4x RHI (11 each) | 13 min | 345.6, 346.1, 346.6, 347.1, 347.6, 348.1, 348.6, 349.1, 349.6, 350.1, 350.6 | -2.0-60 this starts ~20 minutes before 01, 07, 13, and 19 UTC |
| | | | RHI (1) | 0.5 min | 348.1 | -2.0-60 |
| | | | VPT | 6 min | | 90 |
| | | | PPI | 1 min | 280-360 | 0.0, 5.0, 10.0 |
| | | | 4x RHI (11 each) | 13 min | 345.6, 346.1, 346.6, 347.1, 347.6, 348.1, 348.6, 349.1, 349.6, 350.1, 350.6 | -2.0-60 |

**Table 7**. Overview of the ARM quality control process. Both engineering and data teams oversee the radar quality at different operation stages.

| Stages | Preparation for operation | During operations | Data post-process |
|---|---|---|---|
| **Goal** | Engineering calibration for radar system | Operation monitoring for radar data stability and data collection | Data quality control and correction for quantitative applications of c-level data products |
| **Who** | Engineer and technician team | Engineer and technician team, Radar data team, and data quality office | Radar data team |
| **Radar data output** | | Raw, a-level data after automatic ingest, engineer works, missing/problematic data reports to DQA, DQPRs and DQRs | b-level data |
| **Working items** | Laboratory hardware tests and signal processing design, e.g., receiver sensitivity etc.<br>Onsite solar calibration for accurate antenna pointing positions and receivers<br>Onsite corner reflector calibration for radar system calibrations<br>Scanning strategy design/test | Automatic data collection and ingest monitoring system<br>Radar hardware parameters monitoring<br>Qualitatively evaluating radar measured variables meet expected characteristics<br>Quantitatively examine radar reflectivity stability and dual-polarimetric performances through ground clutters, ZDR bias estimation, instrument intercomparison, etc.<br>Identify non-meteorological echoes<br>*engineering calibration processes may be conducted during operations | Mask for non-meteorological echoes<br>Providing b1-level corrected reflectivity (Z) and differential reflectivity (ZDR) data<br>Data uncertainties discussion: ship movements, wet radome, interference, etc. |

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