Artifacts Observed in ARM Radar Datasets

Marqi Rocque[1], Ya-Chien Feng[1], Israel Silber[1]

[1]Pacific Northwest National Laboratory, Atmospheric, Climate, and Earth Sciences Division

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Introduction to ARM Radars

The Atmospheric Radiation Measurement (ARM) user facility operates several cloud and precipitation radars at each of its three fixed sites. Radars are also frequently deployed with ARM's mobile facilities for shorter duration field campaigns. ARM radars span a wide range of frequencies and have both vertically-pointing and scanning capabilities. Currently, each site has a zenith pointing cloud radar known as a KAZR. Additional scanning cloud radars known as SACRs are or will be operational for the EPCAPE and CAPE-K field campaigns (AMF1 and AMF2) and the Bankhead National Forest observatory (AMF3). Additional precipitation radars will be operational this spring at NSA and Bankhead.

ARM Radar Acronyms

Vertically-Pointing

MWACR	Marine W-band ARM Cloud Radar
KAZR	Ka-band ARM Zenith Radar

Scanning - Cloud

WSACR	W-band Scanning ARM Cloud Radar
KaSACR	Ka-band Scanning ARM Cloud Radar
XSACR	X-band Scanning ARM Cloud Radar

Scanning - Precipitation

XSAPR	X-band Scanning ARM Precipitation Radar
CSAPR	C-band Scanning ARM Precipitation Radar

2024 ARM Radar Operations

Site Name*	Radars
ENA	KAZR2
NSA	KAZR, XSAPR
SGP	KAZR
AMF1 (EPCAPE)	KAZR1.5, WSACR, KaSACR
AMF2 (CAPE-K)	KAZR1.5, MWACR
AMF3 (Bankhead)	KAZR2, KaSACR, XSACR, CSAPR2

*see table at bottom for more info

Types of Radar Artifacts

While the majority of atmospheric scientists are interested in clouds and precipitation observed by radars, other potentially less desirable artifacts can also be seen. This includes, but is not limited to:

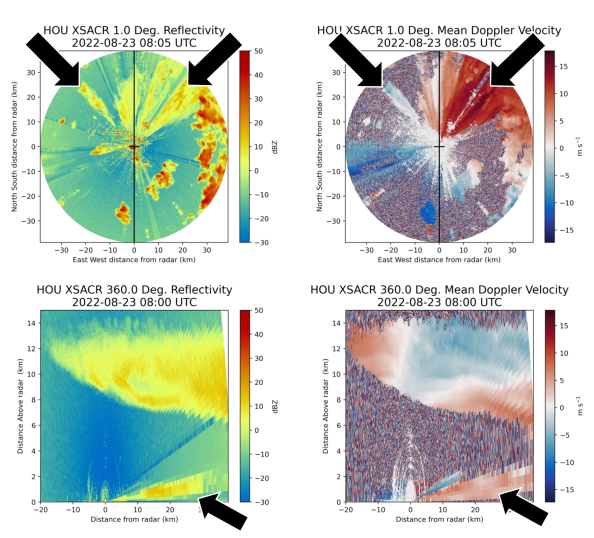
- **Second trip echoes**
- **Interference**
- **Biota (insects and birds)**
- **Ground clutter and terrain**
- **Sidelobes**

Examples of these artifacts observed by ARM radars are shown below. Masks for some of these artifacts have been developed and are available in some b1- and c1-level datasets. The ARM radar team is continuously working on refining these masks by improving our physical understanding of radar artifacts and through machine learning techniques.

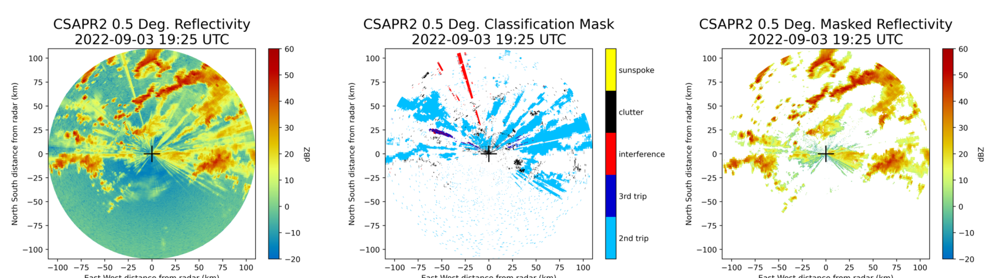
Second Trip Echoes and Interference

The maximum unambiguous range of a radar depends on the pulse repetition frequency, or the number of pulses emitted within a given time frame. Sometimes, echoes beyond the maximum range can appear, but since another pulse has already been emitted, the radar is not able to determine which pulse the return echo is associated with. This results in wedge-shaped features known as second trip.

Second trip echoes detected by the XSACR were widespread during the Tracking Aerosol Convection Interactions Experiment (TRACER) field campaign. PPIs show second trip artifacts north of the radar and more isolated convection to the east. HSRHIs through the second trip depict a wedge-shaped feature near the surface.



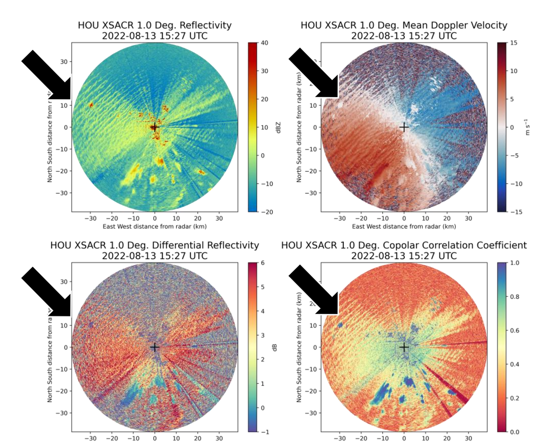
Masking second trip echoes can be challenging. However, the CSAPR2 has a built-in classification mask which identifies second trip, third trip, interference, clutter, and sun spokes. An example of the classification mask is shown below when the CSAPR2 was deployed for TRACER. The CSAPR2 classification mask mainly uses the signal quality index (SQI) to identify second trip (light blue). SQI determines how coherent the return signal is with the transmitted pulse.



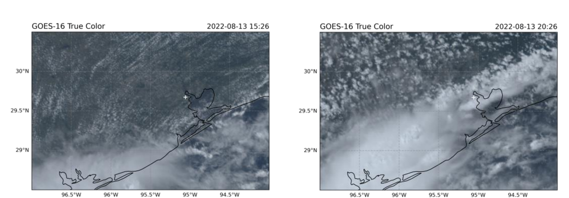
Interference is also identified in this PPI (red). Interference is caused by the radar waves interacting with another continuous wave, often associated with telecommunication links. These artifacts appear as radial spikes and are characterized by low SQI and high normalized standard deviation of received power.

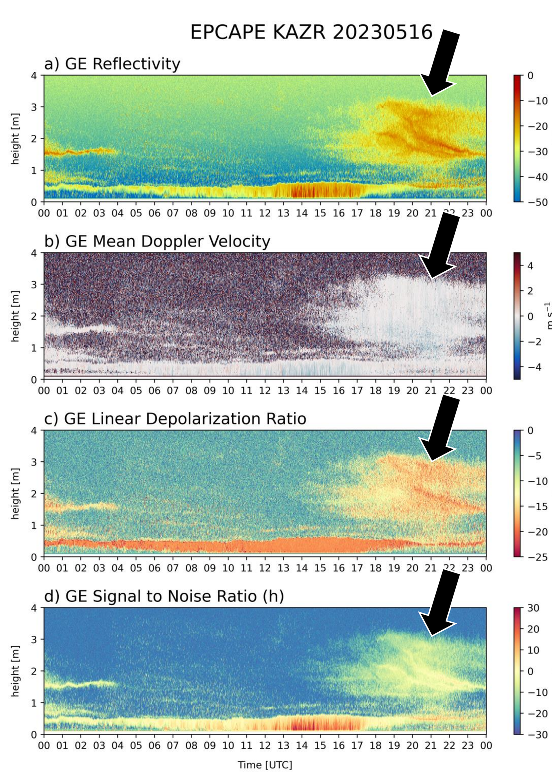
Biota

Biota including insects and birds are also visible by ARM radars. These signatures are most common at warmer sites including SGP (Oklahoma), TRACER (Texas), and EPCAPE (California). They are generally confined to the boundary layer and tend to have diurnal cycles. Biota often have high differential reflectivity (ZDR) values and high linear depolarization ratio (LDR) values because of their horizontal orientation.

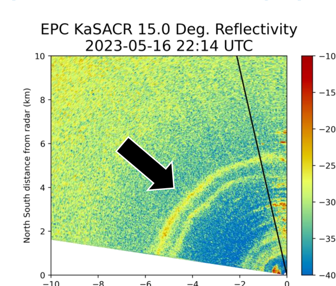


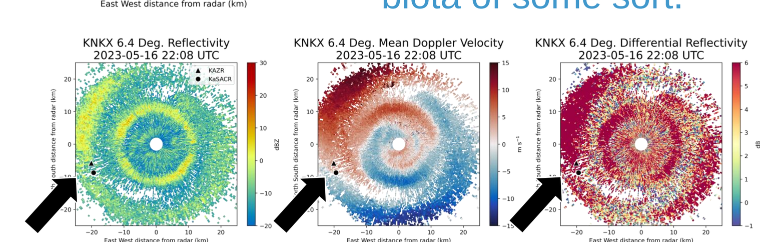
Convective rolls in the boundary layer are observed in the XSACR data from TRACER thanks to insects. These signatures have high ZDR and low correlation coefficient. GOES-16 satellite imagery shows these convective rolls beginning to develop into clouds. Convective rolls precede convection which is observed across the region a few hours later.





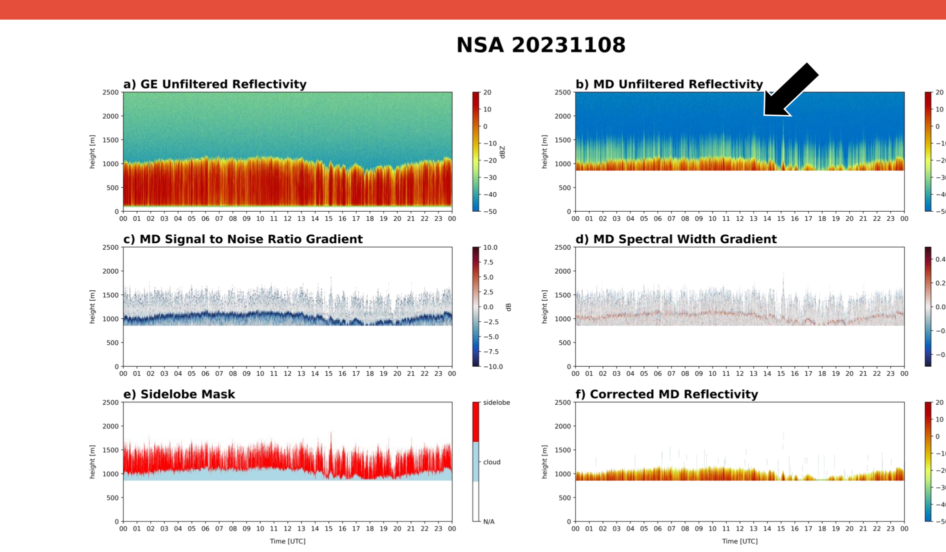
Interesting radar echoes are frequently observed during the day in the KAZR data at EPCAPE. These echoes can extend up to 4 km above ground, often occur with stronger off-shore flow, and are also visible by the KaSACR and the local WSR-88D (KNKX San Diego). While some characteristics such as reflectivity and signal to noise ratio (SNR) are similar in magnitude to clouds, other variables such as LDR (from KAZR) and ZDR (from KNKX) indicate this echo is likely biota of some sort.

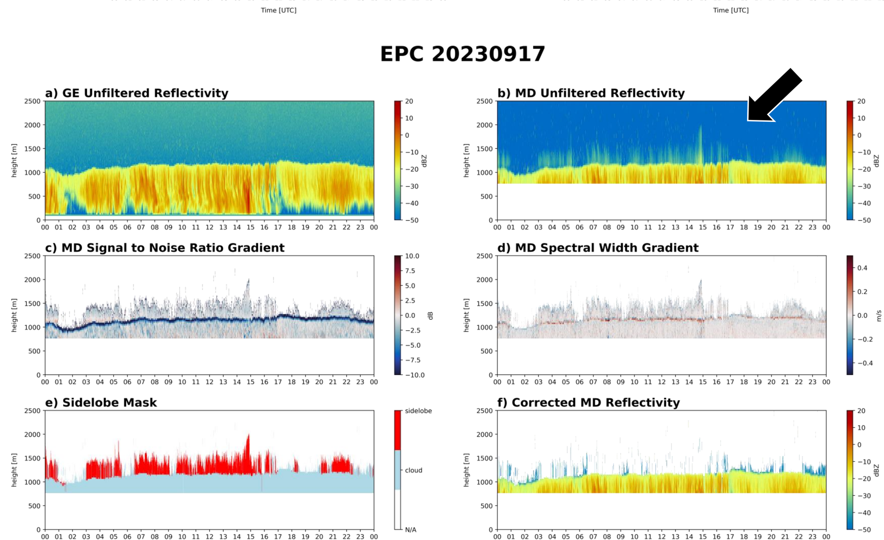




KAZR Sidelobes

The KAZRs have a few different modes of operation, two of which are general mode (GE) and moderate sensitivity mode (MD). The frequency-modulated chirp pulse of the MD mode is longer than the burst pulse of the GE mode and involves complex processing, which results in increased sensitivity but also increased sidelobe impacts. While the lowest levels of the MD mode are masked out, sidelobes can still manifest at cloud top.



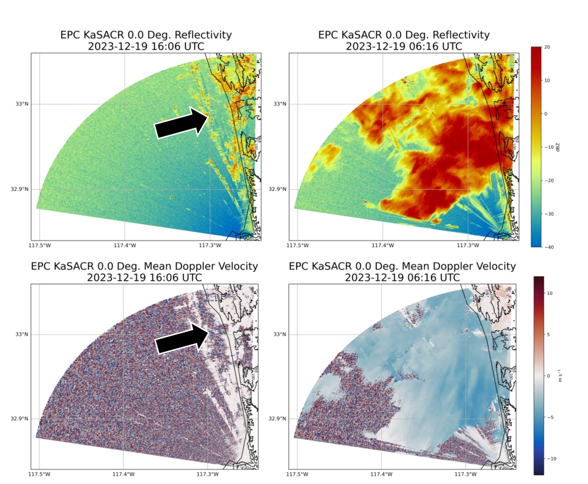


A methodology using the vertical gradient in SNR and the vertical gradient in spectral width has been developed to mask sidelobes. This methodology produces particularly good results at NSA (top) and EPCAPE (bottom) where sidelobe artifacts can be prevalent.

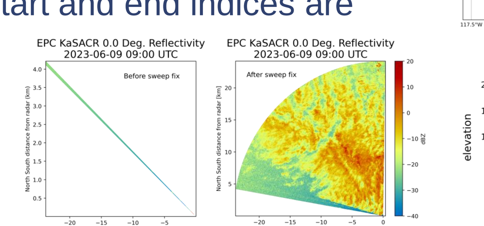
Ground Clutter and Terrain

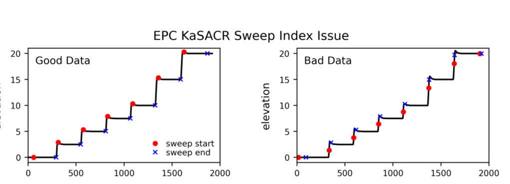
Pulses from radars can reflect off any target including buildings, trees, mountains, and wind turbines. These objects typically have high reflectivity because they are large and have zero Doppler velocity because they are stationary.

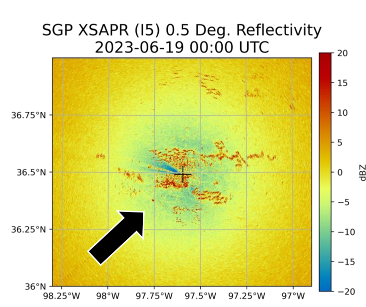
Terrain along the coast of southern California is observed on a clear day by the KaSACR deployed for the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE) field campaign (left). Reflectivity and Doppler velocity of a cloud observed earlier this day is shown for reference (right).

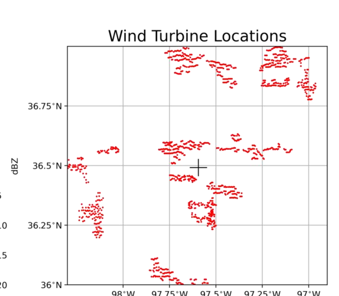


As an aside: The KaSACR at EPCAPE also has an issue where the sweep start and end indices are occasionally incorrect. This issue will be corrected in b1 data and can be manually fixed in a1 data as needed.



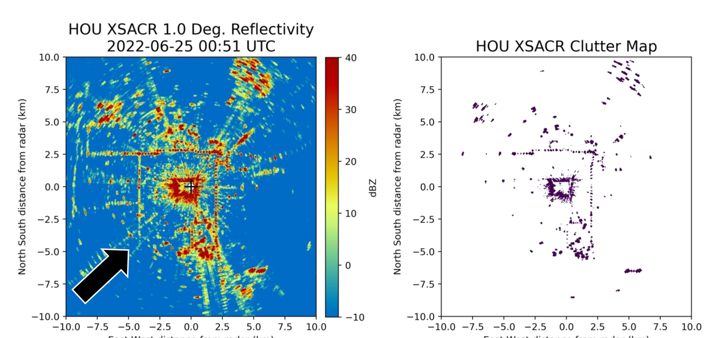






Wind turbines are prevalent at the SGP site in Oklahoma. Higher reflectivity returns from the XSAPR align well with the location of wind turbines from the U.S. Wind Turbine Database.

Significant ground clutter caused by buildings, trees, and lamp poles was observed by the XSACR during TRACER. While ground clutter is not typically desired by most scientists, it can be used to monitor the radar's performance throughout a deployment. The relative calibration adjustment (RCA) method uses the high reflectivity of clutter at low elevations close to the radar to evaluate the stability of the radar and provide a baseline calibration.



ABBR.	Name	Location Name	Latitude,	Longitude	Dates
ENA	Eastern North Atlantic	Graciosa Island, Azores, Portugal	39.09,	-29.03	2013 – present
NSA	Northern Slope of Alaska	Utqiaġvik, Alaska, USA	71.32,	-156.60	1997 – present
SGP	Southern Great Plains	Lamont, Oklahoma, USA	36.61,	-97.49	1993 – present
AMF1	ARM Mobile Facility 1	La Jolla, California, USA (currently for EPCAPE)	32.87,	-117.26	Feb. 2023 – Feb. 2024
AMF2	ARM Mobile Facility 2	Tasmania, Australia (for CAPE-K in 2024)	-40.68,	144.69	Apr. 2024 – Sep. 2025
AMF3	ARM Mobile Facility 3	Bankhead National Forest, Alabama, USA (exp. 2023)	34.34,	-87.34	Exp. 2023 – 2028

The TRACER b1 radar data release is currently underway.

The SAIL and EPCAPE b1 radar data releases are anticipated before the end of FY24.

Scan this QR code to learn more about ARM radar operations in 2024.

For additional information or questions:
Marqi Rocque | marqi.rocque@pnnl.gov
ARM Radar Team | radar@arm.gov