

Intersection of Radar Requirements and Scientific Advancement

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Building on the Science: From Frontiers to Priorities

- **Bart Geerts has laid out the emerging science frontiers**
 - Extreme weather, microphysics, QPE, dynamics, BL processes, DA/NWP, climate
- **This talk: pivoting from “what science needs” to “what should we invest in?”**
- **Session charge:** Connect science drivers to technology, identify priorities, understand limitations
- **My framing to promote discussion: Given budget realities, how do we maximize scientific return?**
 - Put forth strawman strategic priorities: phased array, mobile radars, profiling radars, lower-cost systems, and AI/data



The budget reality

- **Flat or declining federal research budgets demand strategic choices**
 - NEXRAD is our largest national radar resource, facing next-gen NEXRAD replacement
 - NSF FARE facility model provides access, places resources selected platforms
 - Interagency coordination (NSF, NOAA, DOD, NASA, DOE) remains fragmented, and may be more difficult now
- **We cannot fund everything. But we should be bold. What are the highest-leverage investments?**
- **Discussion:** How do we balance transformative ambition against fiscal realism? What existing programs show the best return on investment? How do we learn from others and leverage better collaboration and new technologies?

We have tremendous scientific and technological momentum

- Despite the headwinds we face at the federal level, we have tremendous capacity in radar technology the US
- Increasing role of the private sector in hardware, software, operations

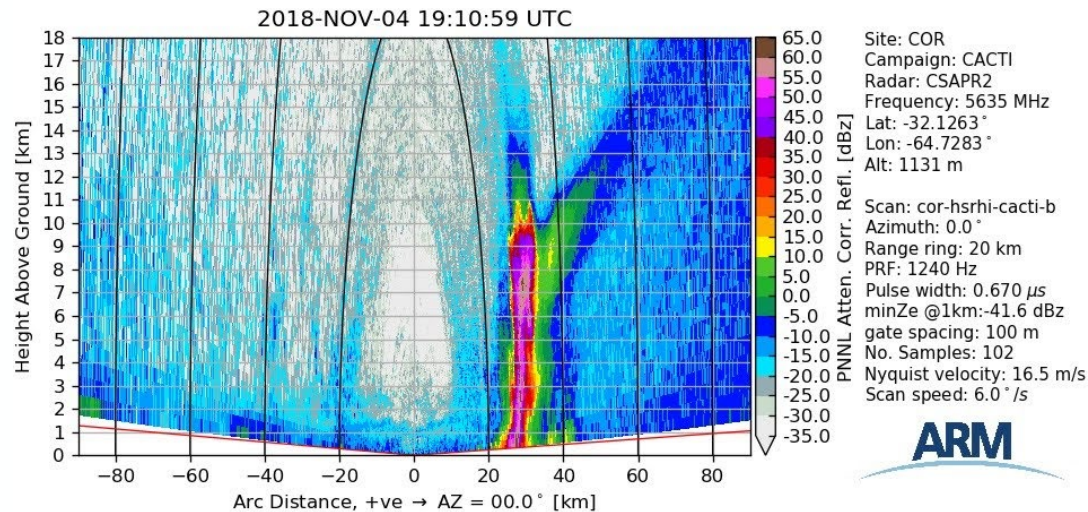
Still, to enable research, we have the opportunity to

- Increase innovation
- Make facilities more usable and available
- Increase quality and value of data collected, accelerate measurements into science and improve models
- Reduce pain points for investigators, facilities
- Increase education and workforce development opportunities

Scientific advancement from the human perspective, speaking as a PI, field campaign PI, and (former) CIF Co-PI

- Field campaign organization is the hardest thing I've ever done, and in the current NSF structure, PIs are left to do more of it than in the past
- Technology incubation is difficult to get started at a University
- Managing data (particularly *open data*) can be hard at a university
- Managing a facility at a university is also hard
 - Institutional headwinds can make it harder (risk, reputation, bureaucracy, budgets, etc.)
- NCAR can play important roles in helping us in each of these areas
 - Can democratize access to resources & expertise that individual universities can't

Now, with this background, moving towards our charge of assessing the landscape...



- In the rest of this talk, with the science fresh in our minds, I'm here to “spike” discussion towards our breakouts and help us discuss priorities and strategies for radar technology development.
- Wen Chau will discuss “the APAR experience” in the next talk, but let's discuss these areas for now...

Advancing Phased Array Technology

Existing Efforts to Build On

- NOAA NSSL Advanced Technology Demonstrator (ATD)
- Lincoln Lab phased array weather radar program
- HORUS, KaRVIR, etc. at OU
- SBU, soon OSU X-band phased array

Key Challenges

- Cost per unit: 2-5x mechanical systems
- Polarimetric data quality (planar arrays), alternatives?
- Scan strategy optimization/imaging still an active area of research
- Not (yet) needed for a sizeable part of radar meteorology studies

Paths Forward

- Leverage existing testbeds rather than starting new programs
- Focus on adaptive scanning for research applications
- Sub-minute volumes enabling rapid-update DA

Discussion:

- How can Phased Array radar development and community involvement, and instrument availability be promoted by NSF?
- How can this be done well in a constrained funding environment?



Mobile/Deployable Radar Deployment Priorities

Lots of assets

- NSF (FARE): FARM, RaXPol, SEA-POL, UAH, SBU
- NOAA: NSSL mobile assets
- DOE: ARM mobile facilities
- Other university-owned systems (UW, OSU, UMass, CSU, ...)
- Government and commercial gap-filling radars (e.g., Climavision)

Flagship “big” radars

- We still need (relatively) unattenuated scanning radars for severe weather and precipitation research that can be deployed to remote locations
- S-band vs. C-band and associated tradeoffs
- Do we need a deployable 1 degree S-band system?

The Containerization Opportunity?

- Miniaturized/containerized/off grid systems reduce logistics barriers
- Off-grid capable for remote deployments
- Easier import/export across borders

Toward Shared Infrastructure? Enhanced coordination?

- Encourage joint deployment planning and consortia across agencies to reduce PI burden
- Shared maintenance, calibration, and operator training
- Cost-sharing models that reduce per-agency burden

Discussion:

- What interagency mechanisms could facilitate shared mobile radar deployments? Is more/better coordination feasible?



More Easily Deployable Profiling Radars

Democratizing Access to Radar

- ARM has dedicated resources to profiling radar capabilities for long-term and shorter term deployments
- Ka-band and W-band profilers are now affordable enough to replicate, multi-wavelength
- Micro Rain Radars, XPR-style profilers fill critical gaps
- Complement scanning radars with continuous vertical profiling for PBL, cloud dynamics, microphysics

Easily Transportable and Importable

- Small footprint, low power requirements, potential for educational deployments
- Reduce export control and import license barriers
- Enable global deployment: tropics, mountains, at sea

Discussion: What is the minimum viable profiling radar network? How many sites, what frequencies?



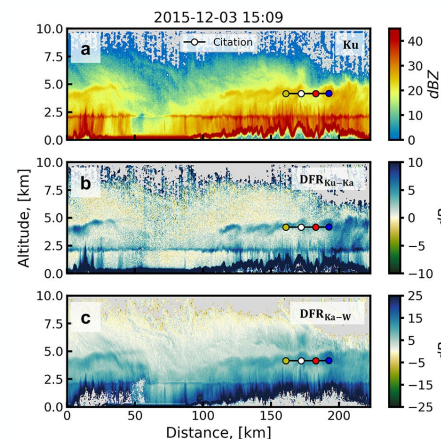
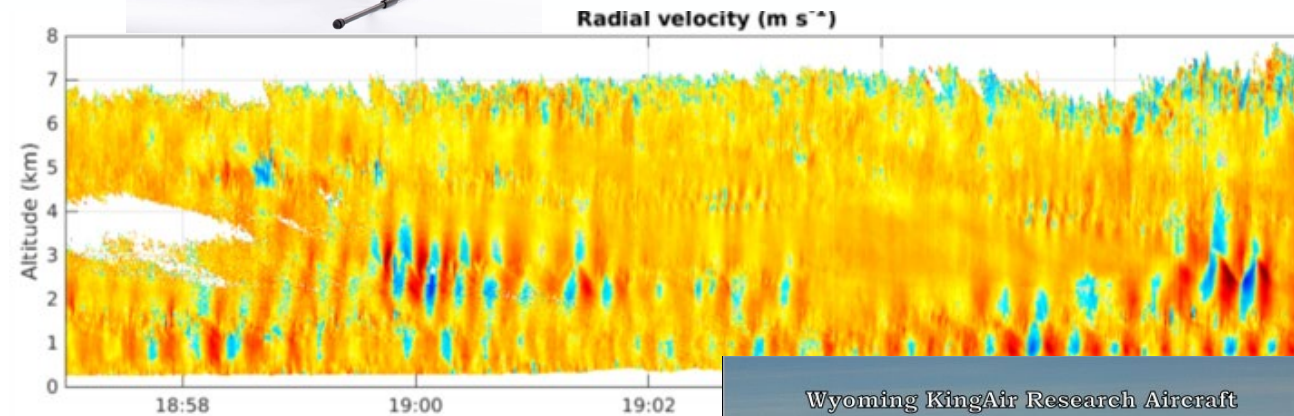
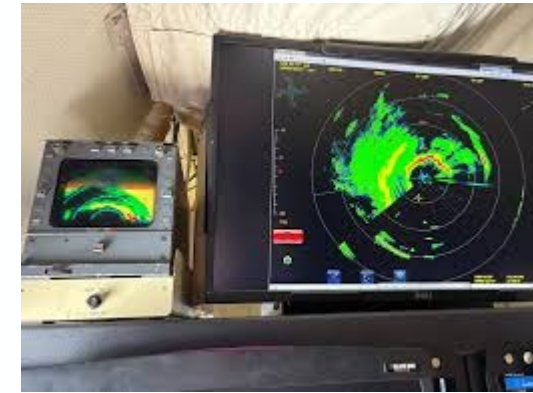
Airborne radar advances

Legacy systems are aging, moving forward from APAR

- Flagship NSF APAR (Airborne Phased Array Radar)-like system envisioned as a key resource
- NSF/university platforms: UWyo King Air (WCR/KPR), NSF/NCAR HIAPER (HCR)
- NOAA P-3 radars: proven for hurricane reconnaissance
- NASA has unique multi-wavelength capabilities on 777, WB-57, P3
- Unique access to oceanic, remote, and over-storm environments no ground system can reach

Capacity building and technology

- Prioritize re-envisioning NSF flagship airborne radar
- New technologies: Leverage uncrewed aerial systems (UAS or balloon-based) for boundary layer/cloud radar sensing, multi-wavelength & novel scanning strategies
- **Discussion:** Weighting of re-envisioning flagship airborne radar (phased or non-phased array, developing new small systems for UAV/balloons, sustaining existing aircraft platforms? Optimizing use of aircraft in field campaigns?



Data+AI as a Force Multiplier for Radar Science

Exploiting decades of existing data

- 35+ years of NEXRAD data, decades of research radar archives largely untapped for AI/ML
- Foundation models for radar: self-supervised pre-training on large archives
- Applications: signal processing/QC, hydrometeor classification, nowcasting, super-resolution, gap-filling

AI for experimental design, optimization of data collection

- AI for observing system simulation experiments
- AI for scan optimization, targeting scientific objectives (Phased Array)

The Critical Prerequisite: ARCO-Format Data

- Analysis-Ready, Cloud-Optimized (ARCO) formats are essential for AI at scale
- Current archives: heterogeneous formats, inconsistent QC, fragmented access
- Investment in data stewardship and format conversion has outsized returns
- Open-source tools (Py-ART, LROSE, wradlib) + CfRadial2/Zarr/DataTree as standards

Discussion: Who funds the conversion of legacy archives to ARCO? How do we ensure physical constraints in ML architectures? What collaboration models with CS/AI community work best?



```
2026-02-01T21:06:48.866458Z W@W icechunk::storage:object_store: The LocalFileSystem storage
will attempt to commit at the same time, prefer using object stores.
at icechunk/src/storage/object_store.rs:75

# Open as xarray Dataset
ds = xr.open_zarr(
    session_store,
    group="spatial",
    zarr_format=3,
    consolidated=False,
)
ds
```

xarray.Dataset

Dimensions: (time: 3, latitude: 3500, longitude: 7000, height: 19)

Coordinates:

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longitude	(longitude)	Float64	230.0 230.0 230.0 ... 300...
height	(height)	Float32	500.0 1e+03 ... 1.8e+04 1...

Data variables:

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Attributes: (10)

Toward Community Prioritization

There are other priorities – we are here to gather input!

1. Advance phased array through existing programs — don't start from scratch?
2. Prioritize interagency mobile radar coordination — maximize existing fleet utilization?
3. Invest in easily deployable profiling radars — democratize access, enable global science?
4. Airborne radar systems — invest in flagship systems, maintain platform diversity, invest in new technology?
5. Fund ARCO data conversion and AI infrastructure — highest ROI per dollar invested?

Cross-cutting: Open-source software (Py-ART, LROSE, wradlib) and standardized formats (CfRadial2) are foundational infrastructure requiring sustained support

Discussion: Over to you! What's missing? How do we advocate for these priorities in the current funding landscape?



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Thank you

2026 NCAR Radar Workshop

