

# Science Drivers for Future Ground-based and Mobile Radars

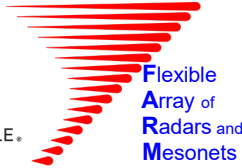
Joshua Wurman, Karen Kosiba

Flexible Array of Radars and Mesonets (FARM) / UAH

*What we might  
merely want*

**Vs**

*What we  
really need*



## **Need** versus **Want** in a **Zero-Sum** World

NSF funding is a ~ **zero-sum** game (at best)

**University Grants + CIF + LAOF + NCAR + MRI  $\approx$  constant**

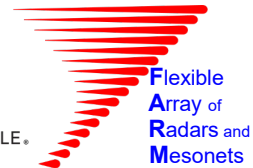
It is easy at a workshop like this to say

“We need A,B,C,D, ..., M, N, O, ... X, Y, Z”

“Any cuts will cripple science, the country, the world”

**But, there aren't \$ for A,B,C,D,E,F,G,H,IJ,K,L,M,N,O,P,Q,R,S,T,U,V,W,X,Y,Z**

We are tasked with communicating community radar needs/priorities  
**... what NSF should prioritize**

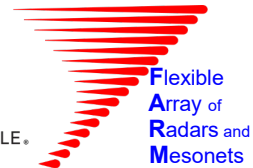


# Saying “all radars matter” isn’t useful guidance to NSF.

## 2023 FARE Workshop BAMS said this:

- Invest in cm-wavelength **Phased-Array Radar (PAR)** architecture development, including fully digital designs, to explore adding polarimetry and the ability to emulate various PAR architectures effectively (Fulton et al. 2016).
- Maintain access to **fully-mobile, flexible weather radars operating at X- to S-band frequency**, given the significant utilization in numerous Track 1 and Track 3 FARE proposals.
- Provide access to beam-matched **multi-wavelength radars**, which are useful for characterizing mixed-phase clouds and ice habits, density, shape, and size.
- Explore integration of ground-based or **airborne G-band radars**, to better characterize boundary-layer and cirrus clouds.
- Foster development of **Differential Absorption Radar (DAR)** Technique, leveraging multiple radar frequencies near a water vapor absorption line (e.g., 183 or 325 GHz) to profile water vapor (e.g., Lamer et al. 2021) and characterize cirrus clouds effectively.
- Invest in **Wind Profilers with Passive Multistatic Radars**, offering a cost-effective solution for a network of 3D wind profiles.
- Encourage open-source radar **software** development like Lidar-Radar Open Software Environment (LROSE, <http://lrose.net/>) and Py-ART (<https://arm-doe.github.io/pyart/>).
- Ensure open and easy access to **large radar datasets**, particularly from previous field campaigns, to facilitate cross-cutting research.

Every advocate got their bullet (some even with citations...I’m jealous).



# 2012 Radar Community Workshop:

RECOMMENDATIONS. “To address high-priority research topics, specific radars on specific platforms will be required....”

“The following findings and recommendations are *not ordered according to priority...*”

- Polarimetric radars
- S-band, Bragg scattering radars
- Operational refractivity measurements
- A transportable (trailer towed) radar (CIRPAS)
- Airborne Electra Doppler Radar (ELDORA)-like radars
- Airborne Phased-Array Radar (APAR)
- A diversity of radar platforms at several wavelengths.
- There already is a good mix of truck-mounted mobile radars (including rapid-scan radars) at various wavelengths (C, X, Ka/Ku, and W bands),
- Multiple radars mounted on the same platform
- Multiple-wavelength airborne radars.
- A very high-frequency (VHF) profiling system with Bragg scattering capabilities for boundary layer applications
- A network of deployable profilers
- Thermodynamic profiling radars a
- Cloud (high frequency) radars are needed
- Ship-based radars and perhaps buoy-borne radars
- Deployable networks of radars and other instruments
- Mobile networks of radars are valuable facilities that need to be maintained rather than developed.
- Gap-filling radars with easier deployment capabilities
- Networks in urban areas are also needed to study and monitor air pollution processes, particularly, as noted earlier, in clear air.
- Emerging phased-array technology,
- CASA-type radar networks
- Better software tools

As my kids say in the socials .... OMG

Full Disclosure: No DOW or FARM person has ever been invited to plan such meetings, or to author the reports.

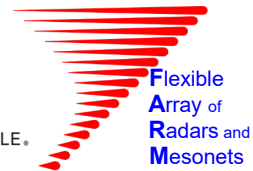
These “all radars are important” recommendations happen because **nearly everyone here is COI:**

- Working at an institution which running or developing radars
- Recently graduated from/ worked at such institutions
- Recently co-authored, co-awarded/co-projected with someone from such institutions

Evaluating impacts, which **drive** priorities, comes down to a global Science Traceability Matrix

- Which capabilities are mainly niche?
- Which capabilities are “nice” but not critical?
- Which capabilities have the broadest impact?

Since cost is a factor (**zero-sum**),  
**which capabilities should be prioritized?**



I'm going to say things here which go against the grain of "technology-ists", "technophiles".

I fancy myself as "Mr. Weather Radar Technology".

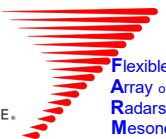
My career is based on my inventions of radar technology.

- I got a job at NCAR saying I wanted to make a bistatic network.
- I got a job at OU saying that I wanted to make DOWs.
- I lead FARM, a radar-technology centered facility.
- I made the 1st rapid-scan mobile radar
  
- My scientific contributions have been much more picking low-hanging fruit with my inventions, not conceptual inspirations.

**I am super-pro new-technology.**

Technology is interesting. Technology is fun.

When I take a shower, I daydream about cool new technological things.



**BUT**

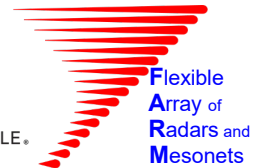
# What are the main scientific questions which require radar observations?

## What are the necessary observables?

- Winds
  - Vector Winds
- Dual-Polarization Parameters
  - ZDR
  - Phi-DP/KDP
  - LDR
- Multiple wavelengths
- Thermodynamic
  - Refractivity
  - Buoyancy

## What are the necessary (not just nice) qualities of these observables?

- Resolution
  - Temporal
  - Spatial
- Duration: e.g., through a supercell or BL evolution lifecycle
- Spatial extent: e.g., along a lot of a squall line or snow band
- Near-ground-ness
- Storm-top-ness
- Off-shore, road-remote
- Penetration through heavy precipitation
- Clear-Air sensitivity

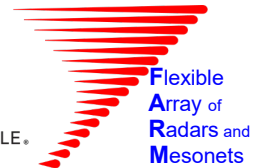


## For example, what observables and qualities of these observables do I need for my scientific endeavors?

My, and colleagues (especially Karen here in the audience) scientific foci have included:

The following are pretty niche interests:

- Tornado vortex structure 100 s x 20 m x 50 m AGL
- Rapid tornado structure evolution 10 s x 20 m x 50 m AGL
- Multiple-vortex behavior and structure 10 s x 30 m x 50 m AGL
- Low-level tornado winds 50 s x 10 m x 10 m AGL
- Rapid evolution of low-level tornado winds 10 s x 10 m x 10 m AGL (just 2D)
- Rapid evolution of 3D tornado structure 10 s x 10 m x 10 m AGL
- Tornado intensity 100 s x 20 m x 50 m AGL
- Hurricane Tornado-Scale Vortices 20 s x 50 m x 100 m AGL
- Tornadogenesis (when, where, etc.) increasing forecastability 60 s x 300 m x 150 m AGL
- Tornado evolution (which ones will get strong) increasing forecastability
- Hurricane Boundary Layer Rolls and Fluxes and Wind/Damage relationships 50 s x 50 m x 50 m AGL
- Snowband evolution 100 s x 100 m x 100 m AGL
- We just wrote a paper about bugs (real, six-legged bugs) in an eclipse 30 s x 100 m x 50 m AGL

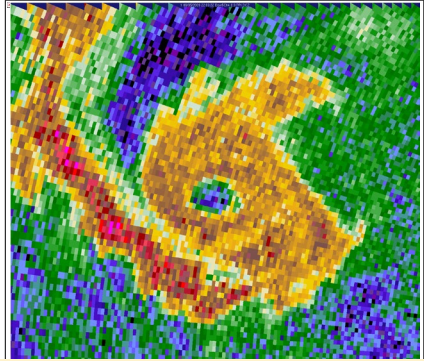


# I like Rapid-Scan technology:

- Rapid-Scan DOW: 11-m gates: volumes as fast as the antenna can spin.

We are one of the main consumers (drivers) of Rapid-Scan.

But....Mostly.... we don't need super-fast observations.



7-sec volumes Goshen Tornado

## The more impactful foci of tornado science

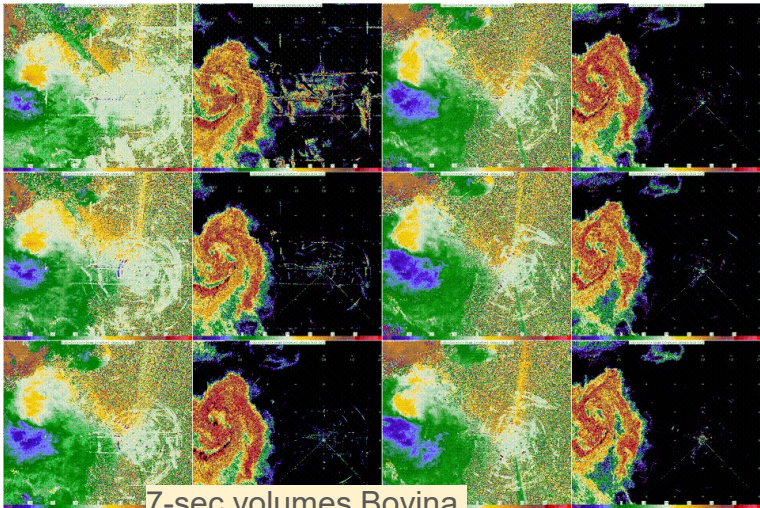
- Tornadogenesis
- Tornado evolution

Do not require more or better rapid-scan radars.

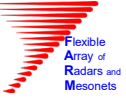
For most of my interests, we probably need:

- ~ 50 m resolution,
- ~ 50 s updates,
- ~ 50 m near the ground, and vectors

50 x 50 x 50



7-sec volumes Bovina Tornadoes



## What do other scientific foci need most?

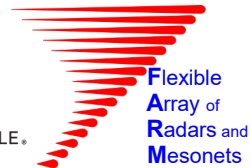
We aren't experts in everyone's science.

We've tried to glean the highest priorities from:

- Award abstracts
- BAMS
- Websites
- Other papers
- Other “surveys”, e.g., Bodine and Griffin (2024)

(Very thorough survey. Interesting. I disagree with conclusions, but you should read it.)

The following “drivers” lists are certainly not exhaustive.



## Sample Science Objectives: Convective Initiation

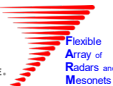
(e.g., IHOP, PECAN, RELAMPAGO, MITTEN-CI)

- Identifying nocturnal convection drivers: 2 - 5 min, 300 - 500 m, near ground - 2 km AGL (e.g., PECAN)
- Identifying environmental conditions, mesoscale influences, and local topography that can help predict location and timing of CI: 3 min, 300 m, near ground - 2 km AGL (e.g., RELAMPAGO); 1.5 min, 300 - 500 m, near ground - 2 km AGL (e.g., IHOP)
- Identifying convective initiation processes in midlatitude coastal (lake) regions: 3 min, 50 m, near ground - 1 km AGL (MITTEN-CI)

## Sample Science Objectives: Fire Weather

(e.g., RaDFIRE, Australia Experiments, California Fires)

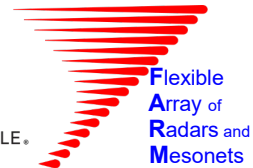
- Rapid evolution of fire plume structures: 10 s probably
- Evolution of pyrocumulus and pyrocumulonimbus: 2min, 100-200 m, near surface
- Rapid evolution and structural evolution of fire vortices: 10 s probably ... 3D maybe
- Generation of internal boundaries promoting wind shifts: 2 min, 100-200 m, near surface



## Sample Science objectives: Winter Precipitation

(e.g., FROST, OWLeS, WINTRE-MIX, SNOWIE, IMPACTS, S2noClime, SNOWSCAPE)

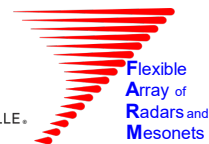
- Evaluating snowband kinematics, structure, and evolution: 3-4 min, 300 m, near surface - 4 km AGL (e.g., OWLeS), 1 min, 300 m (e.g., IMPACTS); 6 min, 300 m (e.g., WINTRE-MIX)
- Evaluating snowband microphysics and precipitation growth mechanisms: 3-4 min, 300 m (e.g., OWLeS), 1 min, 300 m (e.g., IMPACTS); 6 min, 200 m (e.g., WINTRE-MIX)
- Tracking individual lake-effect snowband misovortices: 20s, 50m, 50 m AGL (e.g., OWLeS)
- Evaluating effectiveness of cloud seeding: 5 min, 300 m (e.g., SNOWIE, SNOWSCAPE)
- Evaluation of the macro- and microphysical cloud and snowfall properties in mountainous terrain: 3-6 min, 300m (e.g., S2noClime); 5 min, 300 m (e.g., SNOWIE)
- Microphysical Fingerprints: 1-2 min, 200 - 300 m
- Generating Cells: 2 - 3 min, 200 - 300 m (e.g., FROST)



## Science objectives: Deep Convection (MCSs, QLCS, primarily)

(e.g., PECAN, RELAMPAGO, PRECIP, PERiLS)

- Surface-to-elevated convection transitions: 2-5 min, 300 - 500m (e.g., PECAN)
- Initiation, upscale growth, and dissipation of MCSs: 5 min, 300 - 500m (e.g., PECAN, RELAMPAGO)
- Production of severe surface winds: 5 min, 300 - 500m (e.g., PECAN, RELAMPAGO); 2-5 min, 300 - 500 m (PERiLS)
- QLCS kinematic structure, RIJ, mesovortexgenesis, and tornadogenesis: 2-5 min, 300 - 500 m (e.g., PERiLS)
- Tracking individual tornado vortices: 20s, 50 m, 50 m AGL (PERiLS)
- Identifying environmental, orographic, storm structure, and other factors that promote extreme precipitation events: 6-12 min, 500m (e.g., PRECIP)
- Cold pool generation, properties and propagation: 5 min, 300 - 500m (e.g., PECAN, RELAMPAGO); 2-5 min, 300 - 500 m (PERiLS)
- Microphysical structure and processes: 5 min, 300 - 500m (e.g., PECAN, RELAMPAGO); 2-5 min, 300 - 500 m (PERiLS)



## Science objectives: Hail

(e.g., RELAMPAGO, ICECHIP)

- Diagnosing hail trajectories, storm properties, and favorable environmental conditions that promote hail growth: 2-5 min, 300 m (e.g., RELAMPAGO); 2-3 min, 300 m (e.g., ICECHIP)
- Hail growth zone: < 1min, 300 m (e.g., ICECHIP)

## Science objectives: Lightning

(e.g., STEPS, TELEX, RELAMPAGO, LEE)

- Aligning ice particles during electric field discharge (rapid): **1s**, 100 m
- Lightning bubbles (rapid): < 1 min, 100 m
- Understanding electrification in the presence of wind turbines: 2min, 300 m (e.g., LEE)
- Characterization of precipitation and kinematic structure in relation to charge structure, flash initiation, and lightning polarity: 5 min, 900 m (STEPS); 2-3 min, 800 m (TELEX); 2-5 min, 300 - 500m (RELAMPAGO); 1.5 min, 400m (proposed), 2-3 min



## **Science objectives: Shallow, Non-severe, and Maritime Convection**

(e.g., RICO, DYNAMO, ESCAPE, PICCOLO)

- Understanding the convective life cycle: ~1 min, 300m (ESCAPE)
- Understanding cloud kinematic, microphysical and precipitation processes: ~1 min, 300m (ESCAPE), 3-4 min, 900 m (RICO)
- MJO convection: 15 min, 1 km (e.g., DYNAMO)
- Plume/Thermal Structure, bubbles versus plumes: 10 s updates likely useful

## **Science objectives: Planetary Boundary Layer**

(e.g., IHOP, PECAN, GRAINEX)

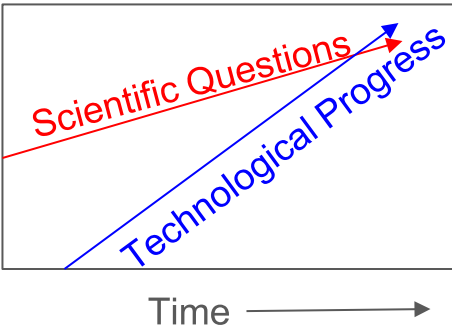
- Evaluating effects of agriculture: 5min, 300m (e.g., GRAINEX)
- Behavior of the LLJ: 2-5 min, 300m (e.g., PECAN)
- Role of bores in promoting or sustaining ongoing convection: 2-5 min, 300m (e.g., PECAN)

Most science objectives, most scientific fruit, can be served by:

regular, existing, or could exist easily, semi-fast and fast radars

Lots of fruit harvestable with: 50 s x 100 m x 100 m AGL radar data

Technology has caught up with scientific needs.  
(I think engineers are smarter than meteorologists.)



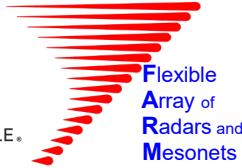
# Is someone thinking,

“no one’s asked for 10-second updates, because all we have are these slower radars”

**Not true:** There are  $\geq 5$  Rapid-Scans (RSDOW, RAXPOL, SKYLER, CPAIR, HORUS)  
(more coming)

- Compared to “regular” DOWs, SRs, NOXP, MAX, how many requests for “exotic”, “niche” rapid-scan or new-technology radar?
- How many by someone who isn’t that radar’s owner?  
(me/UAH, or OU or SUNY requesting their own radars)
- How many requests for “rapid-scan” radars really needed, used, or used as central to a publication, true rapid-scan?

How many “rapid-scanners” used in only **pretty-quick mode**?



“no one’s asked for 10-second updates, because all we have are these slower radars”

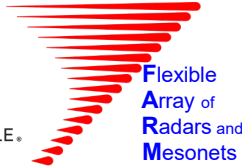
“Pretty-Quick” mode is the most common “rapid-scan” usage

- OWLES had Rapid-Scan DOW: No publications analyze rapid-scan (see Bodine and Griffin 2024)
- Hurricanes (E.g., Isabel, Isaac) had Rapid-Scan DOW: No publications analyze rapid-scan
- ESCAPE had SKYLER and RAXPOL: ... in 1-minute mode ... which regular parabola DOWs can do
- IMPACTS: had SKYLER and RAXPOL:... in modes that regular technology, regular DOW parabola can do
- A future lightning project requests RAXPOL .... *In 90-second update mode.*  
DOWs, regular old conventional-technology DOWs, can easily do 90-second volumes with 12-22 tilts

We can do this with DOW parabolas.

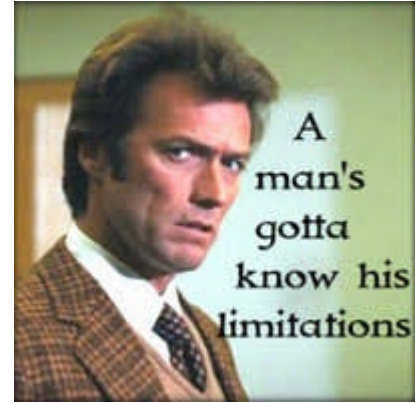
We could pretty easily, pretty cheaply, make DOWs scan 2x faster.

Low cost, low risk



## Fundamental problem is that we aren't smart enough at forecasting mesoscale phenomena.

- CI
- MCS
- Hail
- Tornadoes
- QLCS Tornadoes
- Lake Effect Snowbands



We can't reliably get our small suite of targetable radars close enough.

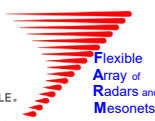
- PECAN people: remember how often the MCS happened near SPOL?
- OWLES people: remember when we deployed where the band wasn't?
- VORTEX2 people: remember those tornadoes outside of the dual-Doppler lobes?
- ICECHIP people: remember those days where the best hail happened > 100 km from the COW?
- ICECHIP people: how many events occurred near the originally-proposed front-range radars?
- RELAMPAGO people: remember all those great storms too far away?
- PERiLS people: remember that bestest tornado far outside the radar array?
- TORUS? ROTATE? Others? You've all been there.

**Our technology is more than good enough.**

**We are not good enough to get what we need from a few targetable (or non-targetable) radars**

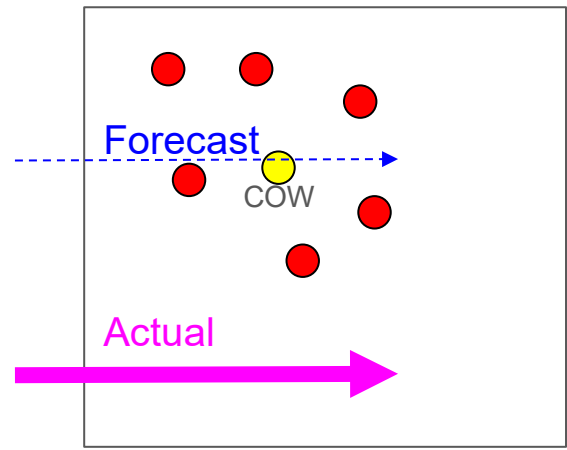
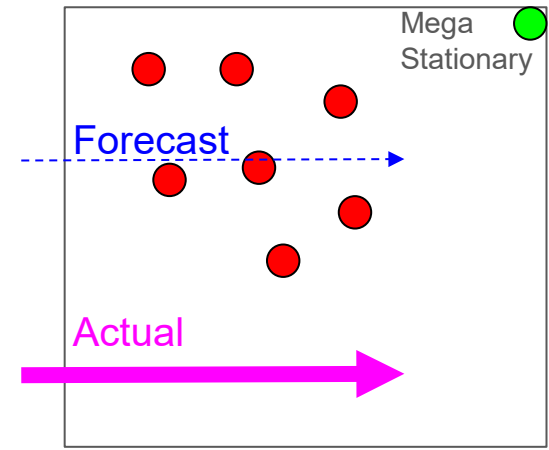
Result is too few cases →

# Case-Study-Itis



Like PECAN,  
VORTEX2, RELAMPAGO  
ICECHIP (as originally proposed)

Like PERILS,  
ICECHIP (as executed)



Probability of  
“successful IOP”  
(really good stuff in  
multiple-Doppler lobes)

0.2 (Mega radar ● deployed in climatologically favored location)

0.4 (because ● can semi-adaptably deploy )

Tons of examples of this. Just picked some in which I personally “felt the pain”

## Case Study Itis:

## Physicists call us Stamp Collectors



For “difficult”, “uncommon” phenomena, we’re all about the case studies

One example. Other field programs probably have similar “demographics”.

V2 publications: 145 (or 256) cite the V2 BAMS paper

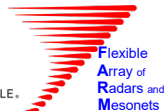
I expired after the 1st 80 reference titles listed on the BAMS site.

- **16 were individual case studies**
- 12 didn’t use radar data
- 37 were other projects/topics citing V2
- **4 (as far as I could tell), were intercomparisons of a few cases (e.g., Snyder dual-pol paper)**
- 4 were “other” or I couldn’t tell from the title

The number of “good” multiple-Doppler cases of active tornadic supercells was very limited, so even the above case studies focused on non-multiple-Doppler data, and some analyzed different aspects of the same case, e.g., Goshen, WY.

**Field project design for uncommon, widely distributed, mesoscale phenomena, is, sadly, often the same as it has been since VORTEX2.**

**“As many mobile radars as we can get, driving around, maybe an anchored radar”**



# Solution: What we should “drive”?

What we need most is a robust, *numerically much larger*, fleet of



- targetable,
- excellent quality,
- excellent reliability,
- professionally-managed,
- inexpensive to operate
- professionally-maintained,
- student-operable,
- professional data quality control,
- efficient network management and tactical control
- inexpensive to maintain



# Cures for Case-Study-Itis



Existing singular Long-wavelength radars



Migrate to



Network of **inexpensive** SOWs +COWs ( FARM poster)

**\$ for these 8 SOWNET / COWNET**

**< \$ for only 2 phased-array mobile Ka-bands**

**Could be done in only 2-3 years !**

Existing small number of regular targetable mobile radars



Expand Qualitatively to

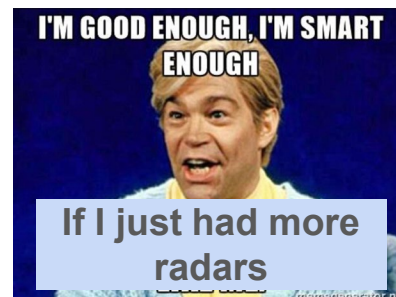
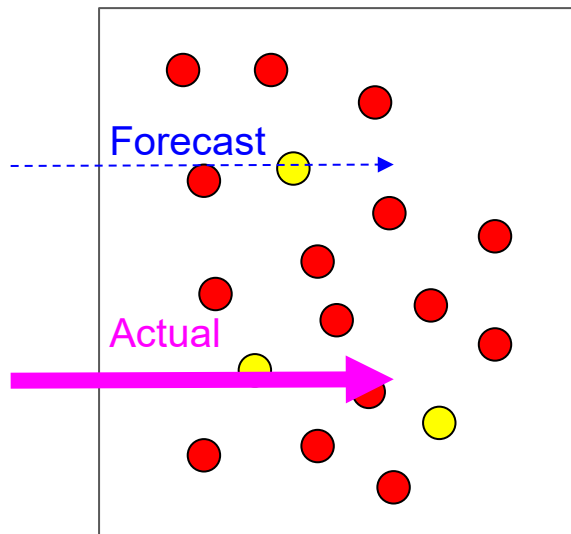


Much larger **inexpensive** network of mobile radars

# Cure for Case-Study-Itis

Future field project design:

Much bigger network of, regular, non-experimental, relatively inexpensive radars



Probability of  
“successful IOP”

0.9 (because we *are* good enough  
if we cast a big enough net)

Seasonal Missions get ~20 “excellent” cases. (e.g., multiple-Doppler + in situ etc.)

“Driving” directions are not black and white. Not 100% / 0%

Important roles for “niche” radars:

**We already have several.**

*or development has already been paid for.*



TTU-Ka, Rapid-Scan DOW, RAXPOL, SKYLERS, CPAIR, HORUS, AIR (retired):

**Primarily serve the scientific needs of PIs at their home institutions.**

Already have *several* rapid scans. X-band, C-band, S-band.

**NSF recently committed \$20M for 2 Ka Rapid-Scan radars (OU's KARVIR)**



**Noble but narrow objectives:**

**thermal bubbles vs plumes, rapid tornado evolution and sub-tornado vortices, turbulent structures, cloud thermals, KH wave rapid evolution**



**Some infrequently used.**

**Some have very long development cycles.** (e.g., PAIR MRI 2015. Testing 2026)

A **subset** of these should be supported (or finished) ..... As a lower priority



“Driving” directions are not black and white. Not 100% vs 0%

**Support Low-Cost Low-Risk Development.** Prioritize High “bang for the buck”

E.g.

**Bistatic:** OU and FARM proposing re-booting bistatic networks: **Low Risk, Low Cost**



**Low Cost  
Low Risk**

**Pod Radars:** OU, FARM, MU have prototype person-deployable radars

**Moderately-Faster dual-freq DOWs:** 100 degrees/sec. 3.5 second tilts, 17 tilts / 60 seconds  
**No new technology, no risk.**

**Ground-DORA:** Using existing stuff, low-cost, low-risk



**Old ELDORA  
RADOME and  
Antennas**



**Tip  
Up**



**Rotate One Panel**



**Add Truck**



**Spin Really  
Fast: 1 Hz**



Enough \$ for implementing large targetable fleet (SOW, COW, DOW)

Could be done in only  
2-3 years !

And, maintain

Existing niche radars (e.g., TTU-K, RAXPOL, SKYLER, CPAIR, RSDOW)

And conduct

*Inexpensive* development

If ... older, less-used, systems are pruned This will be GOOD for NCAR

If ... additional expensive next-generation (air and ground) technology is deprioritized

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The recent CIF model is pretty broken.

**Sub-sustainable** funding for a bunch of systems.

Most efficacious solution is LAOF-style base funding

And, mid-MRI type fleet construction funding.

CIF-sized dinner



University LAOF support would:

- Support critical mass
- Professional staff shared among systems,
- Nurture youthful seeding of innovation,

**For Students**

**3<sup>rd</sup> FARM Radar Institute**

**Hosted by UAH/FARM**

**In-person @ FARM in Boulder**

**July 2026 Exact Dates TBD (soon)**



**Application Deadline:**

**18 April 2026 23:59 MT**

**To: Karen Kosiba**

**[kakosiba@uah.edu](mailto:kakosiba@uah.edu)**

**Questions? Comments? Discussion?**

