Airborne Phased Array Radar (APAR)

The Next Generation Airborne Polarimetric, Doppler Weather Radar

March 6, 2024

Wen-Chau Lee
NSF NCAR Senior Scientist,
APAR Co-PI & Chief Scientist

Everette Joseph
NSF NCAR Director,
APAR PI

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New Award for a Transformative Radar

Our partners:

Multiagency, university and private sector partnership to build APAR.

Science Driver and Motivation

A fundamental challenge in observational meteorology is to measure concurrent 3D winds and precipitation characteristics

Concurrent 3D winds and precipitation characteristics measurements improve understanding and prediction of weather and climate hazards.

1. Microphysics is a poorly understood link in the nonlinear chain of dynamics (circulation) and thermodynamics.
2. Improved representation of microphysics-dynamics coupling in numerical models lets us better quantify storm predictability and reduce uncertainty in climate and earth system models.

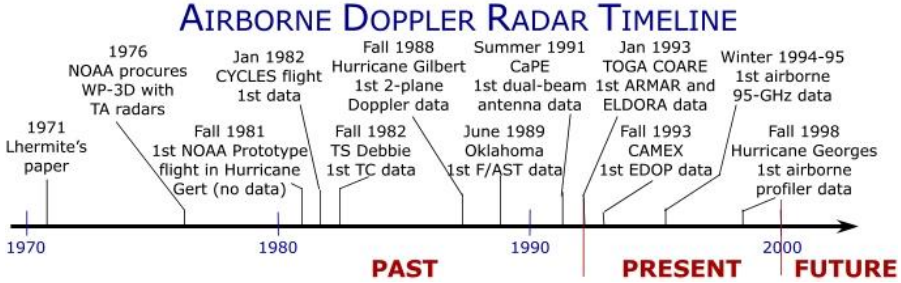
Community Needs and Desired Capabilities

1. The NSF community has expressed the need to have an airborne radar to replace the NSF NCAR Electra Doppler Radar (ELDORA).
2. The effort to better understand and forecast increasing weather extremes has reinforced the demand from the community for having this new advanced airborne radar.
3. Phased array radar technology is mature to measure concurrent 3D winds and dual-Pol parameters and advance science frontiers.

AIRBORNE DOPPLER RADAR DATA ANALYSIS WORKSHOP

BY WEN-CHAU LEE, FRANK D. MARKS, AND CRAIG WALTHER*

Airborne Doppler radar users shared their experiences and methodology in data analysis and their visions for future development of these radar systems.



FUTURE DIRECTIONS. *Infrastructure issues.* Existing Doppler radar facilities may have reached maturity and currently face two major issues. First, the aircraft platforms are getting old: two NOAA WP-3Ds are now 25-yr old, and the NRL P-3 is even older.

Second, is ELDORA the final destination of airborne Doppler radar or just an intermediate stage? Is there a scientific need to push the ELDORA technology forward, given the need for more rapid-scanning antennas to improve the temporal resolution and polarization information for better microphysics inferences? It is probably not too early to think about developing the next generation of airborne Doppler radars. The community needs to leverage resources from different funding agencies [e.g., National Science Foundation (NSF), NOAA, NASA] together to make the development of the next generation airborne Doppler radars happen. New developments in signal processing and phased array antenna design may enable more rapid scanning. These new strategies would mean a redesign and fabrication of the antenna, which will be costly. The group also discussed the possibil-

APAR Concept Presented at the 61st IHC

3 March 2007

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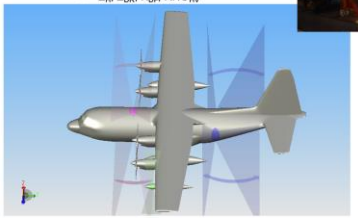
- Four active element scanning array (AESA) conformal antennas
  - C band
- Dual Doppler (V, σ_v)
- 4 x resolution of current system due to simultaneous fore and aft beams from all four antennas
- Dual polarization H,V linear
  - Z_H, Z_{DR}, K_{DP}, RHO_{HV}



MM-Radar
- Dul polarization H,V linear
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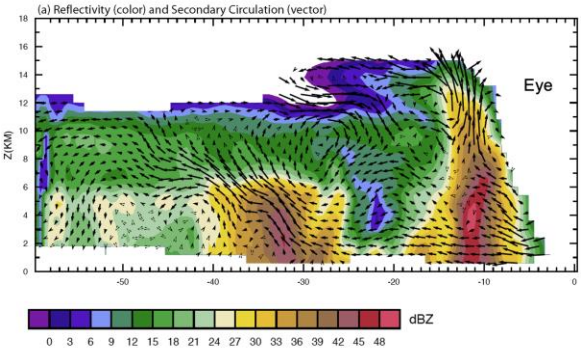
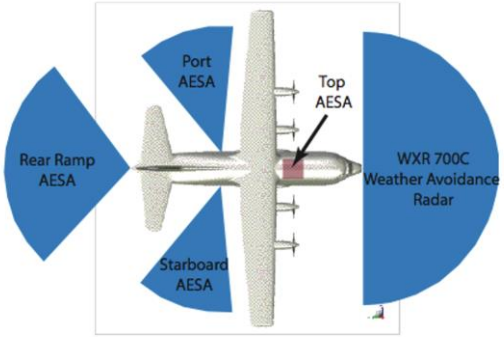
- Dual wavelength (W,Ka)
- Pod-based scanning
- Doppler (V, σ_v)

Vertical X-section in Hurricane Rita at 500 m Resolution (From John Gamache 3D Analysis)



Composite "Surveillance" Scan

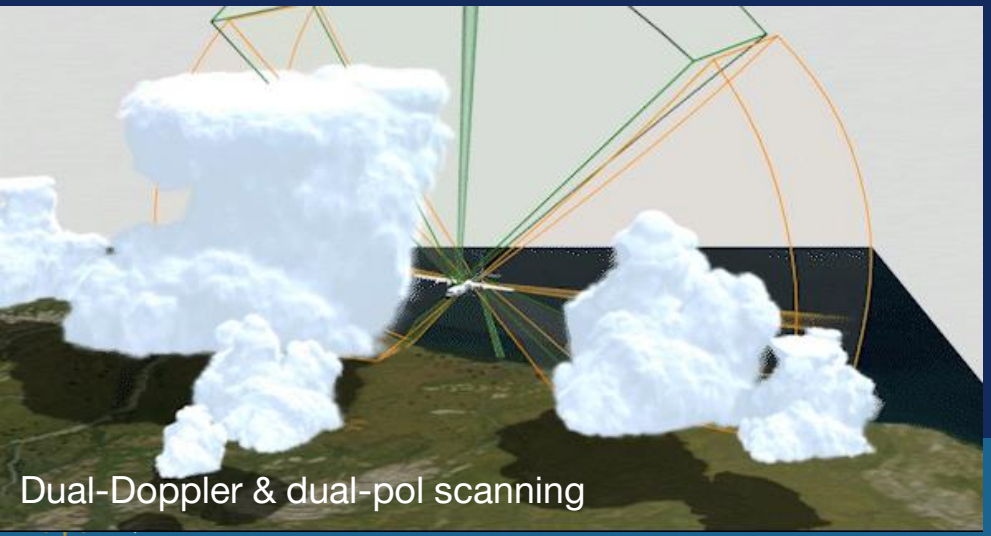


- The AESA radar system can be installed on Air Force C-130s to collect high-resolution 3-D inner core kinematic and microphysical structures during all reconnaissance missions
- Real-time dual-Doppler winds can be transmitted back to NHC and Qced Doppler radar radial velocities and polarimetric data can be transmitted to NCEP for radar data assimilation in hurricane models for every TC that has recon flights
- Generate expanded hurricane database for the Atlantic basin
- Impact the operation and research community - validation of satellite products, process studies, design observing strategy, …

APAR Capability Overview

FIRST-EVER AIRBORNE PHASED ARRAY RADAR (APAR) FOR WEATHER APPLICATIONS

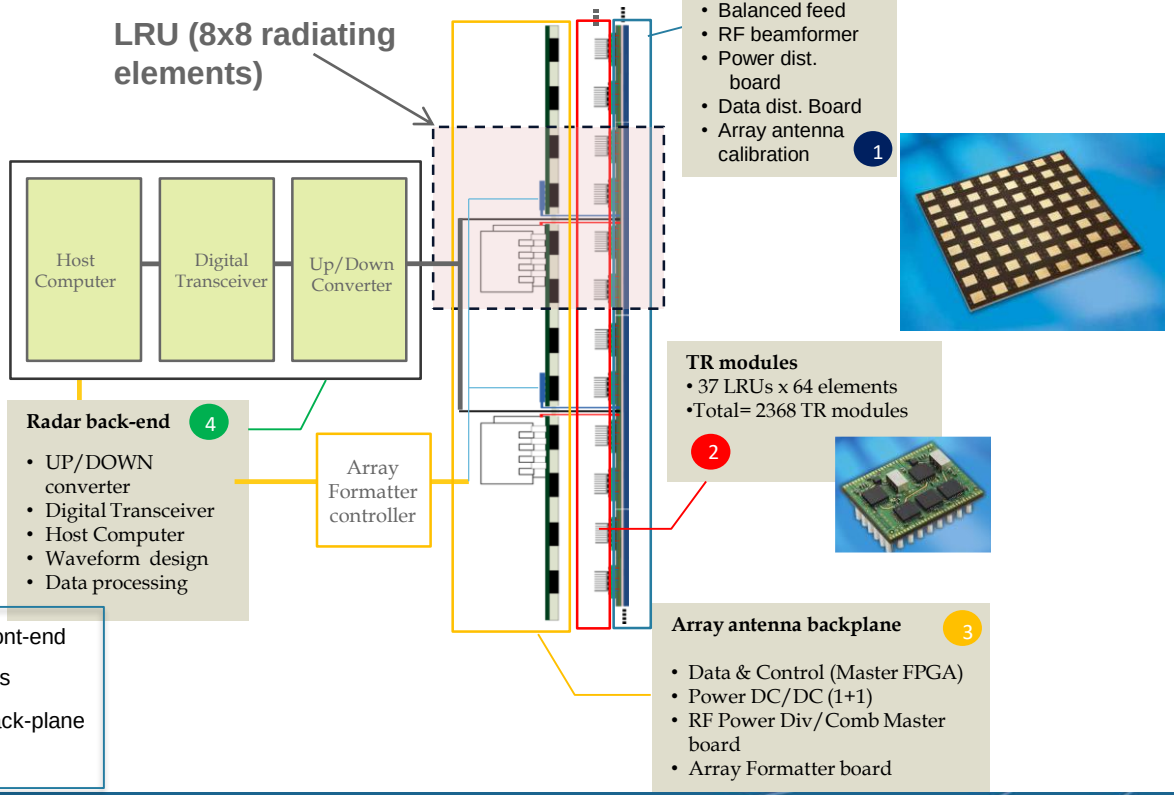
- **Dual Horizontal/Vertical Polarization (Dual-Pol) technology** in at least the horizontal antenna arrays:
  - **Observe** microphysical properties of **clouds** & **hydrometeors**.
  - Critical data to **improve ops forecasts** & understanding of **TC intensity**, extreme precipitation & severe convection.
- Critical **real-time, high-res**, **3D**, atmospheric observations



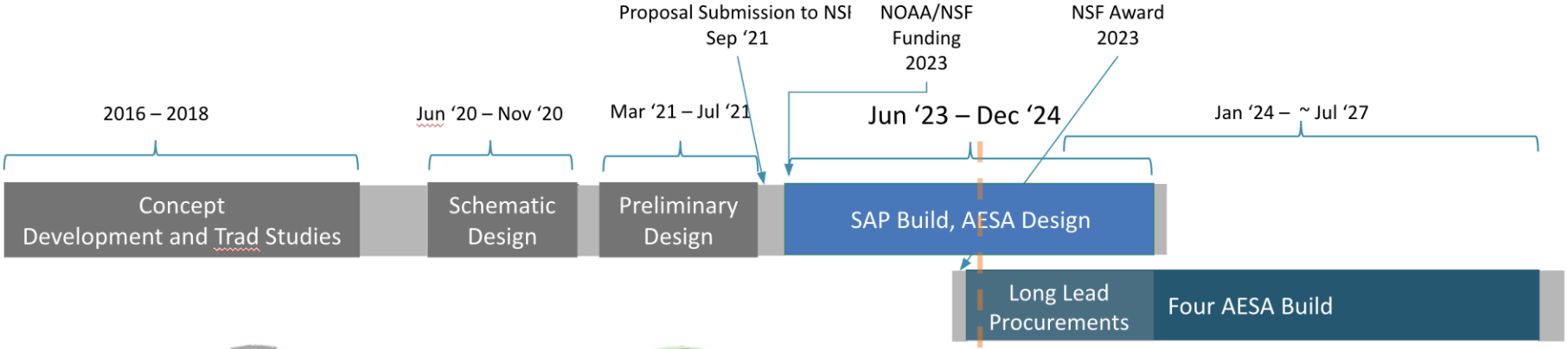
Dual-Doppler & dual-pol scanning

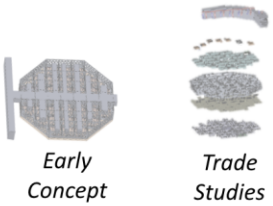
Surveillance scanning (APAR and C-130 nose radar)

APAR Architecture



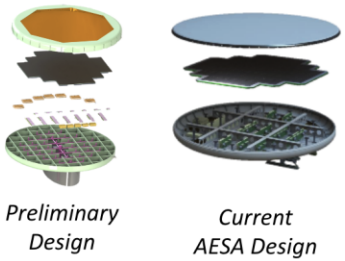
Evolution of the Antenna Design





Early Concept

Trade Studies



Preliminary Design

Current AESA Design

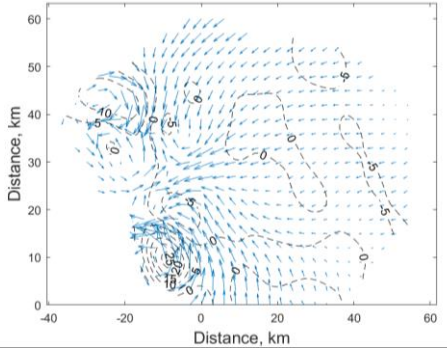
Further info: See Preston McElroy's presentation
"Mechanical Design Challenges & Trade Studies" (up next)

Design maturation over the years

The APAR Observing Simulator (AOS)

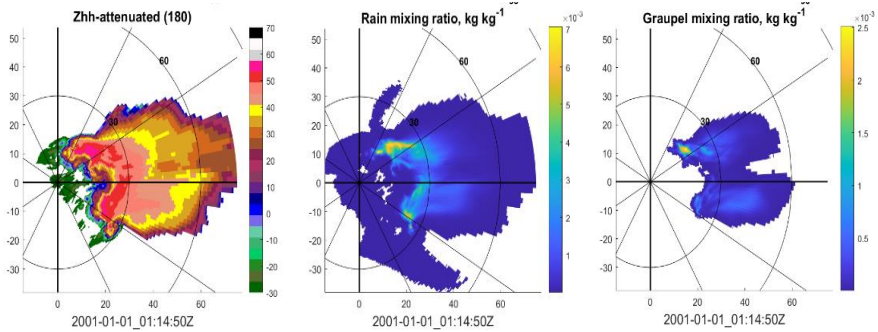
Purpose: Use NWP to simulate how APAR will view high-impact weather events and begin to examine techniques to visualize/analyze data

CM-1 Simulation: Tropical Cyclone, Supercell, and Squall line, at 100 m (except TC) and 500 m grid resolution



Cloud Model 1 (CM1) – MMM

Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation (SAMURAI) - CSU



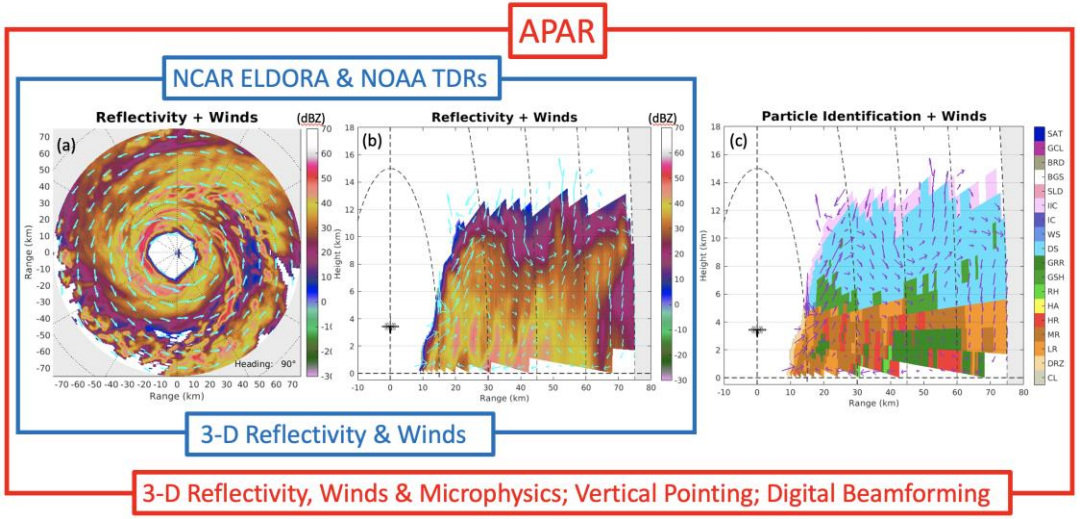
Cloud-resolving model Radar SIMulator (CR-SIM)
Collaboration with the State University of New York at Stony Brook

Use software tools in Lidar Radar Open Source Environment (LROSE) (e.g., CfRadial radar data exchange format, dual-pol and QPE tools, etc.)

APAR Advance Science

APAR

- Improved description of convective and mesoscale storm dynamic and microphysical structures
- More accurate estimate of vertical velocity at high time resolution
- Sample a spectrum of vertical velocity/convergence profiles
- Dwell on the same feature with high temporal and spatial resolution



APAR Suite – Doppler & Aerosol Lidars, Cloud Radar, Radiometer, Dropsonde, In Situ Probes

- Cloud initiation to decay
- Aerosol, entrainment, boundary layer

APAR Suite & numerical models

- Model and process validation
- Improve model microphysics representation

Community Engagement Opportunities

1. Explore scientific frontiers, develop next generation radar analysis software and design innovative field programs using AOS as a testbed – integration and enhance collaboration between observation and model
2. Use AI/machine learning to optimize sampling strategy, data quality control, and data analysis
3. Improve data quality (e.g., sidelobe reduction, surface return mitigation, etc.) via creative beamforming and signal processing techniques
4. Create training program to mentor students and researchers using existing PAR measurement and/or AOS simulated APAR data

Future Vision

2028 NCAR C-130 w/APAR

2030 2 NOAA C-130s + NCAR C-130

2040 10 USAF + 6 NOAA + NCAR C-130s all w/APAR

- **Fleet of APAR-equipped aircraft enabling nearly continuous sampling of TC from genesis to landfall**
- ***Revolutionizing TC reconnaissance and prediction***

A WC-130J Super Hercules aircraft from the 53rd Weather Reconnaissance Squadron sits on the flightline prior to an atmospheric river mission at Travis Air Force Base, Calif.

Questions?


"Ad Audendum"
APAR
Airborne Phased Array Radar
We Dare, So You Don't Have To

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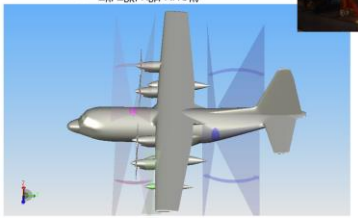

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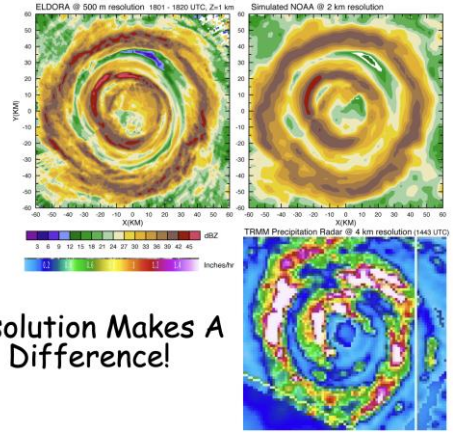

Resolution Makes A Difference!

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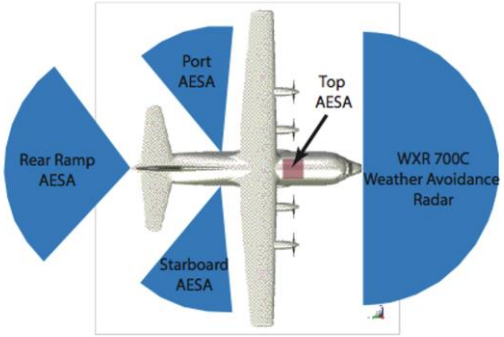

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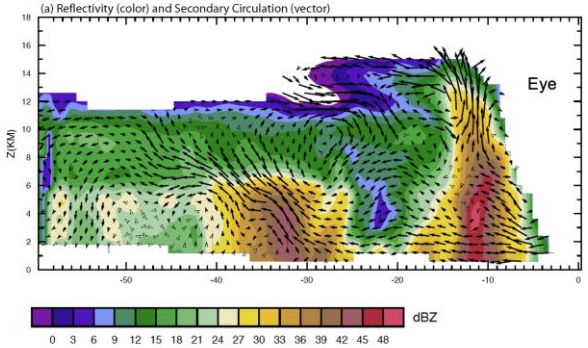


Research 2 Operations

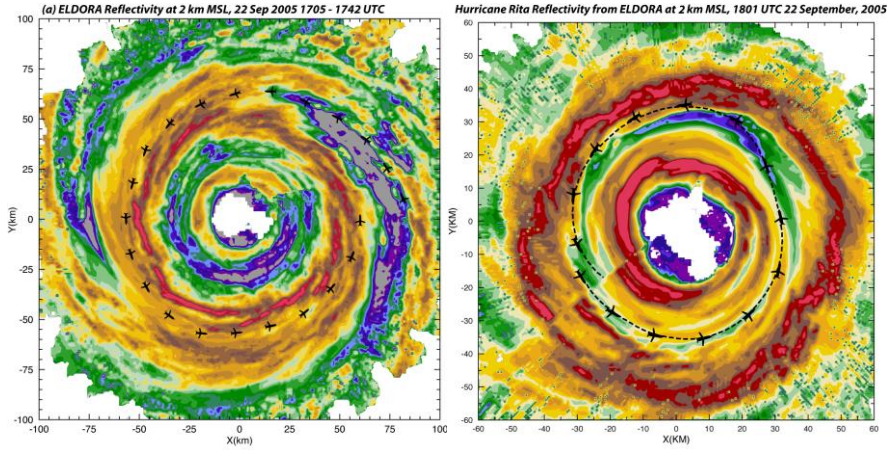
- Improve TC diagnosis by provide 3D kinematic and microphysical structure
- Improve TC track and intensity prediction via assimilating APAR data into NCEP models

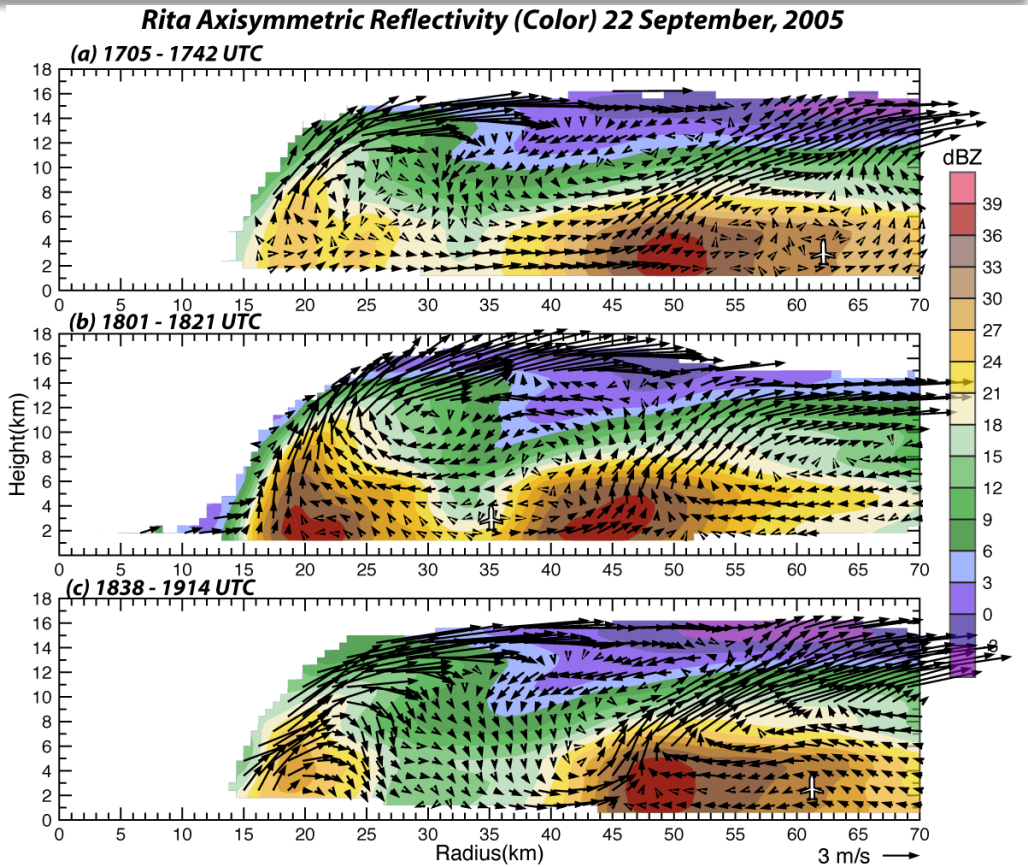
Port to “more recent C-130”?

- Significant investment and upgrades to current NSF/NCAR C-130 will allow at least two more decades of service
- Partnership with NOAA exploring C-130s as alternatives to P-3’s
- Analysis and design required; similarity between C-130H and C-130J increases confidence in transferability of APAR technology

Capabilities of Current Airborne Tail Doppler Radars

First detailed observations of the evolution and structure of a concentric eyewalls and accompanied axisymmetric secondary circulation in Hurricane Rita (2005) (Houze et al. 2008; Science)





APAR Multiplex Bean Scanning

Purpose: Answer critical questions about APAR scanning strategy

Impact: Help define sampling strategy and data quality

Multiplex beam scanning (implemented)

- Uses PAR rapid scanning to observe multiple beam directions during the same interval as a traditional dwell
- Trade-offs between number of beams, data quality and time resolution
- Vivek et al. (2018, IEEE) estimated 6 beams per radar dwell

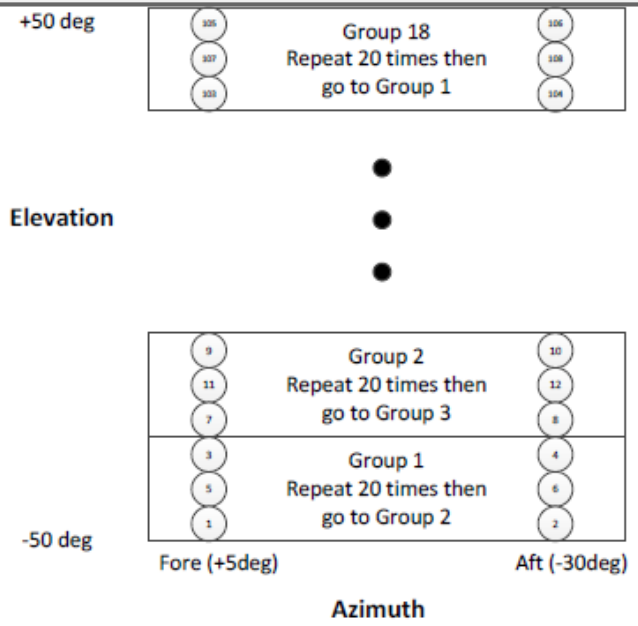
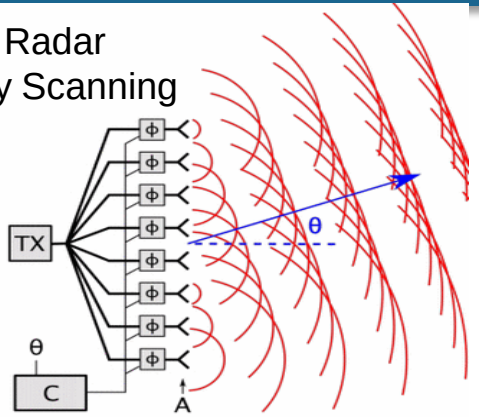


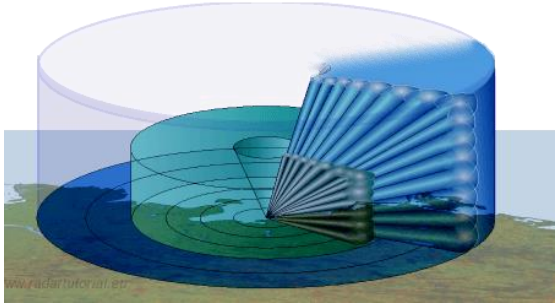
Fig. 8. Possible APAR dual Doppler scan sequence, covering 100° elevation sector with both forward and aft looking beams.

Mechanical and Phased Array Radar

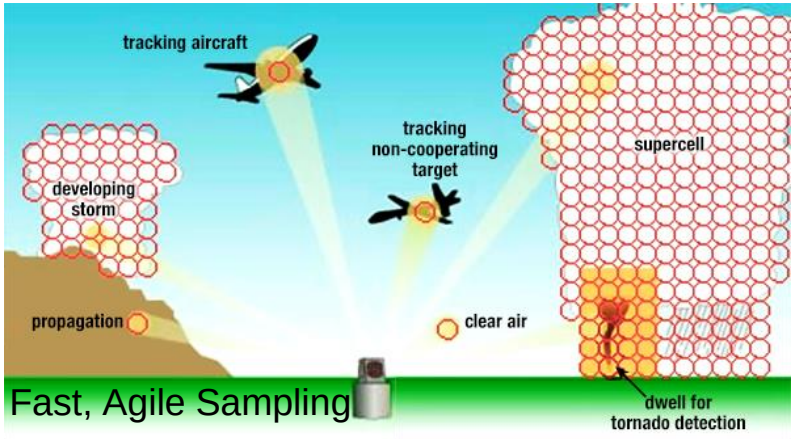
Mechanical Radar
- Sequential Scanning

Phased Array Radar
- Electronically Scanning





Slow, Inflexible Sampling



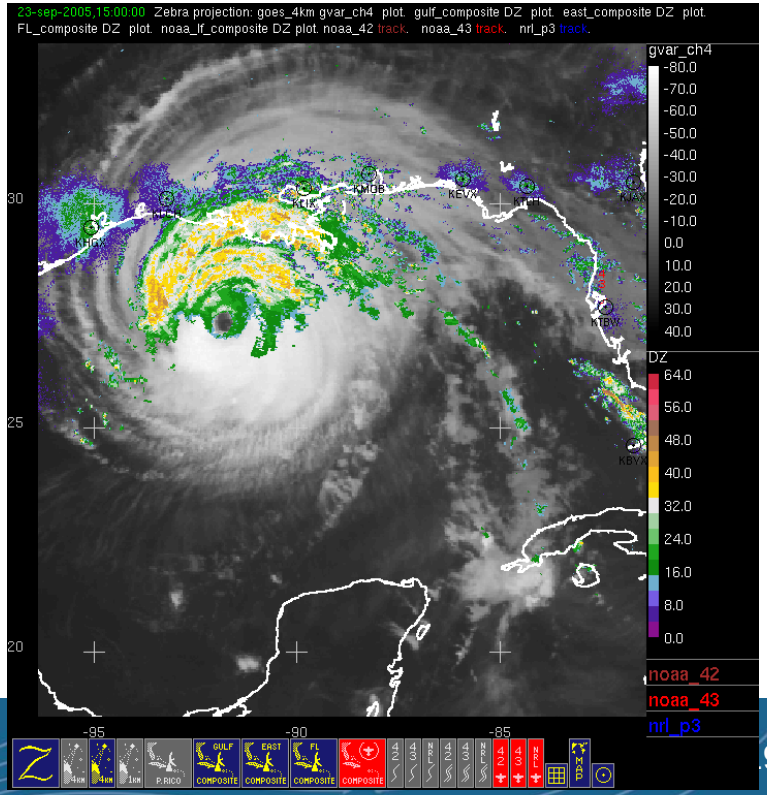
Fast, Agile Sampling

CONOPS

Purpose: Answer critical questions about the deployment of APAR

Impact: Help define requirements, tool for future operations planning

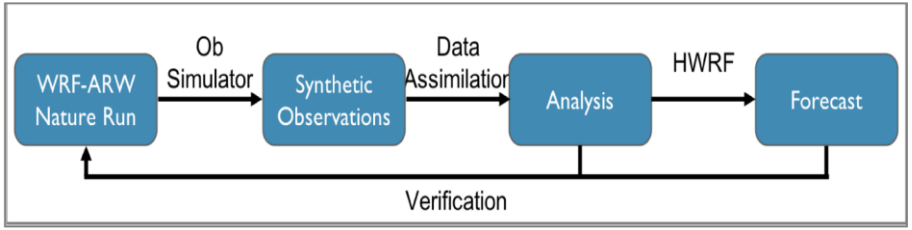
1. Flight strategies for different phenomena
2. Initial scan strategies
3. Deployment considerations / timelines
4. Logistics

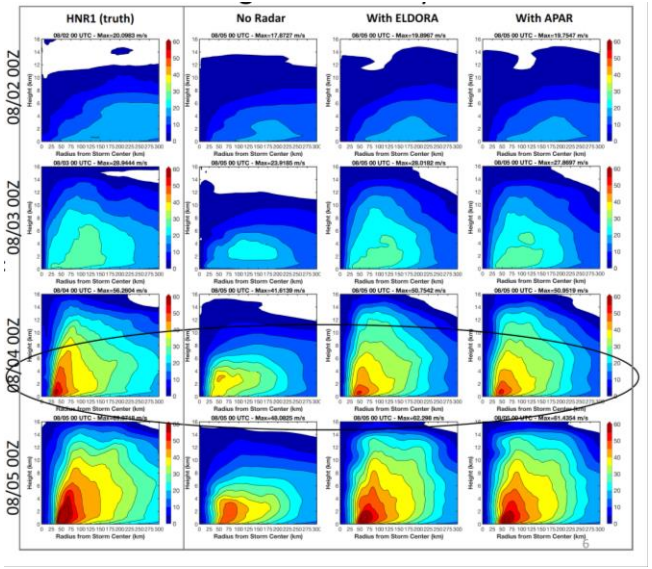


NOAA/AOML APAR OSSE Results

Purpose: HRD effort to understand the impacts of assimilated APAR data on NWP forecasts

Impact: Information on forecast improvement operational procedures





Improvements with radar data

- Stronger maximum winds
- Wind max shifted radially inward and
- Closer to surface
- Deeper vortex

Brittany Dahl[1,2], Lisa Bucci[2], Kelly Ryan[1,2], Peter Dodge[2], Shirley Murillo[2]
1Univ. of Miami/CIMAS, 2NOAA/AOML/HRD