

Science Drivers for Future Airborne and Shipborne Radars



Paul Reasor
NOAA AOML/HRD
Paul.Reasor@noaa.gov

Michael M. Bell
Colorado State University
mmbell@colostate.edu



CSU Sea-Pol
seapol.colostate.edu



NOAA P-3 and G-IV
www.aoml.noaa.gov/



NOAA's Hurricane Field Program: Airborne Tail Doppler Radar (TDR)

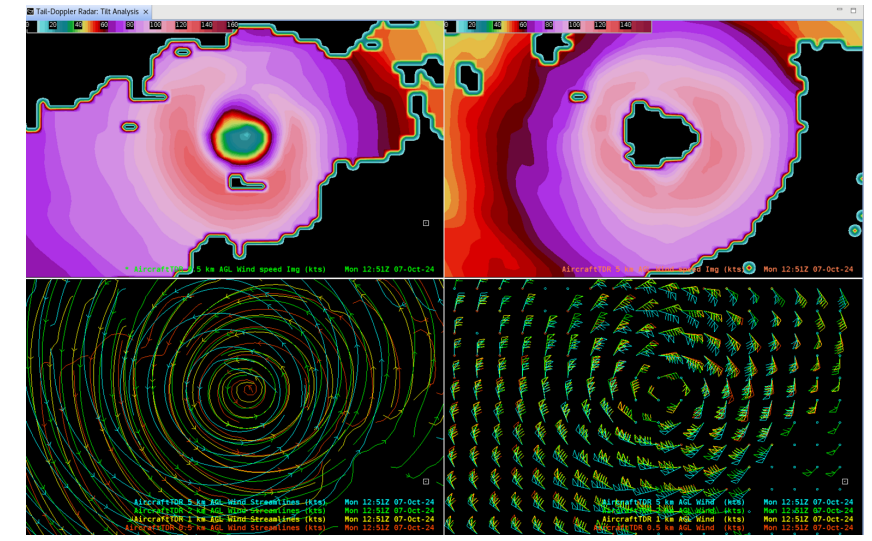
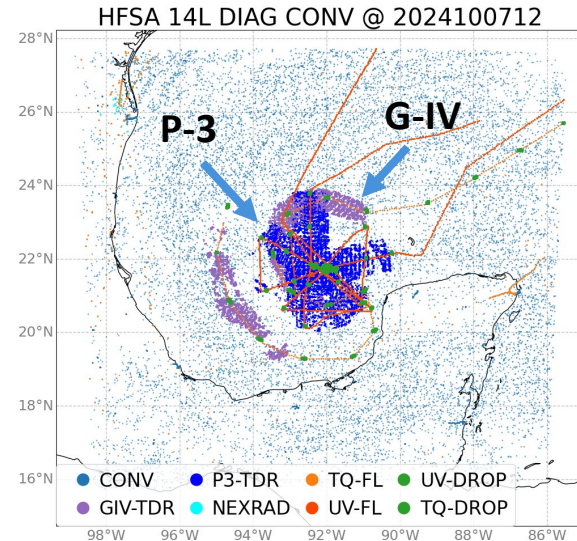
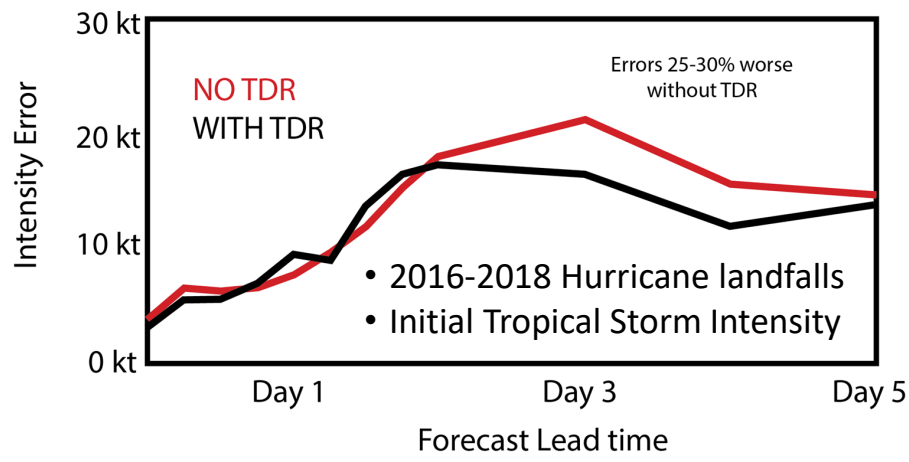


P-3



G-IV

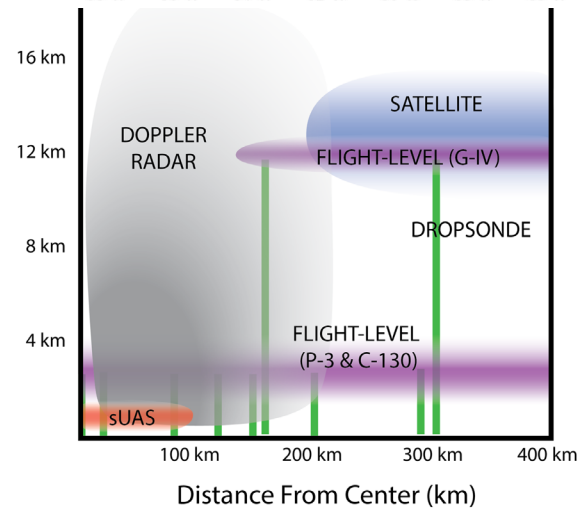
TDR IMPACT ON HWRF FORECASTS



Operations: QC Doppler Radials

- Assimilated by HAFS* (NCEP)
- Bulk of vortex-core wind data
- Impact verification in HAFS ongoing

*Hurricane Analysis and Forecast System

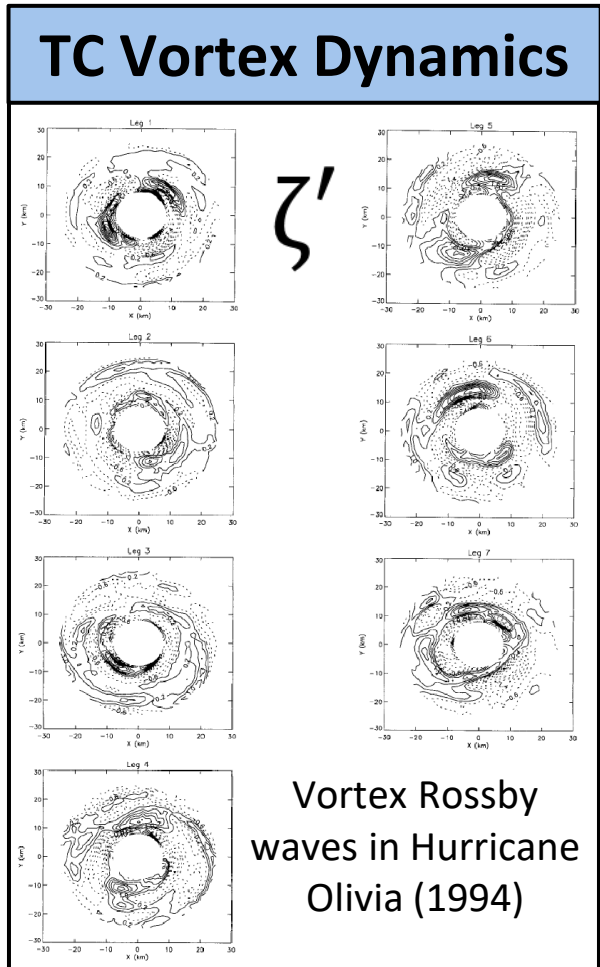


Operations: Analyzed Wind

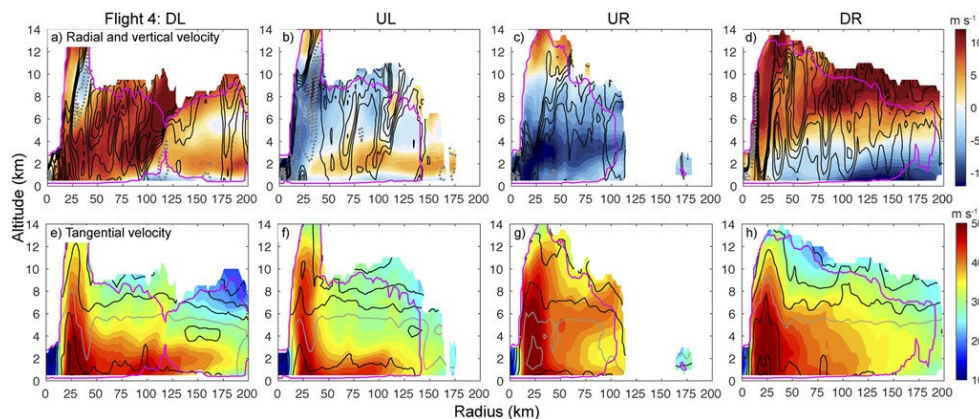
- Ingested by AWIPS* (NHC)
- Structure situational awareness
- TC vortex alignment; Point obs context

*Advanced Weather Interactive Processing System

NOAA's Hurricane Field Program: Airborne Tail Doppler Radar (TDR)



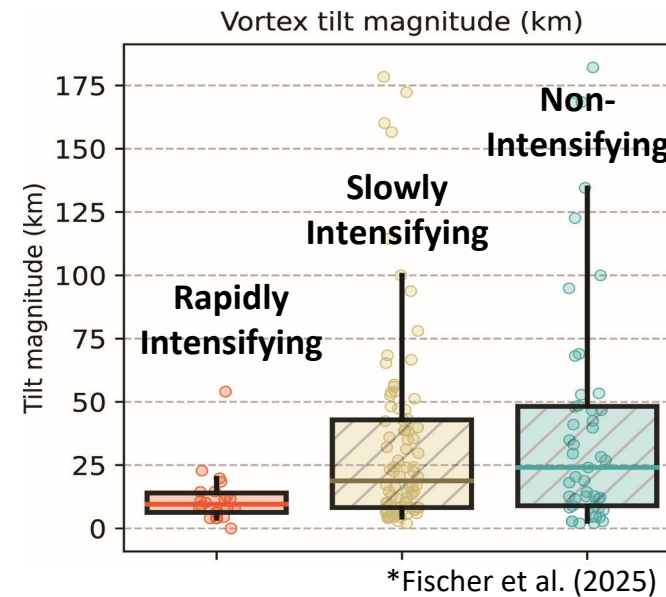
Shear-Organized SEF



Basic Understanding Research

- TC structure
- Secondary Eyewall Formation (SEF)
- Intensification processes

TC Alignment & Intensification



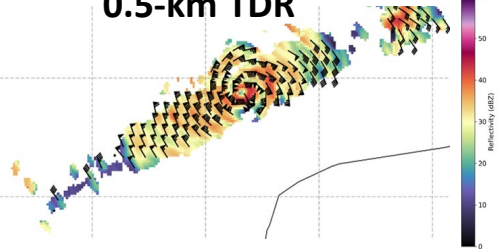
NOAA's Hurricane Field Program: Airborne Tail Doppler Radar (TDR)



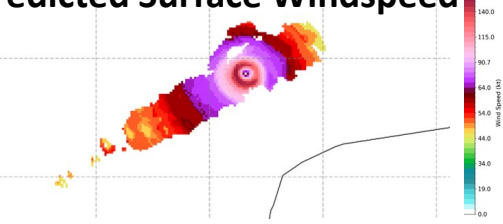
AI-Based Surface Wind Reduction

- ML model trained on dropsonde profiles + environ/vortex params
- Model applied to vertical profiles from TDR analyses

0.5-km TDR



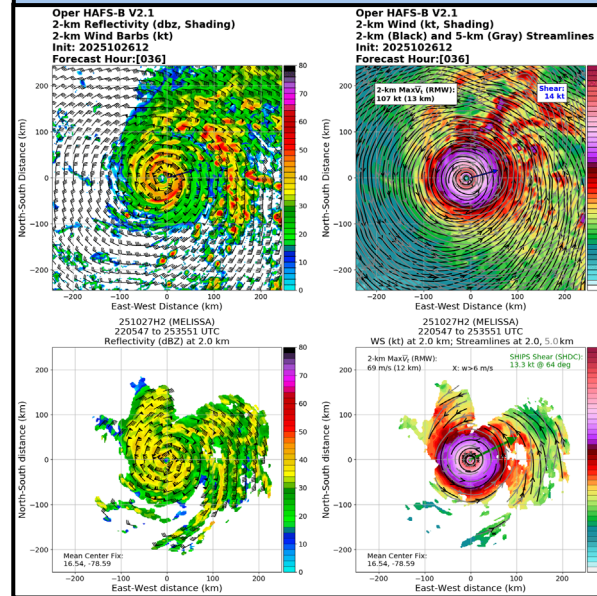
Predicted Surface Windspeed



*J.W. Thiesing & M. Fischer (*in prep*)

HAFS Evaluation

HAFS



TDR

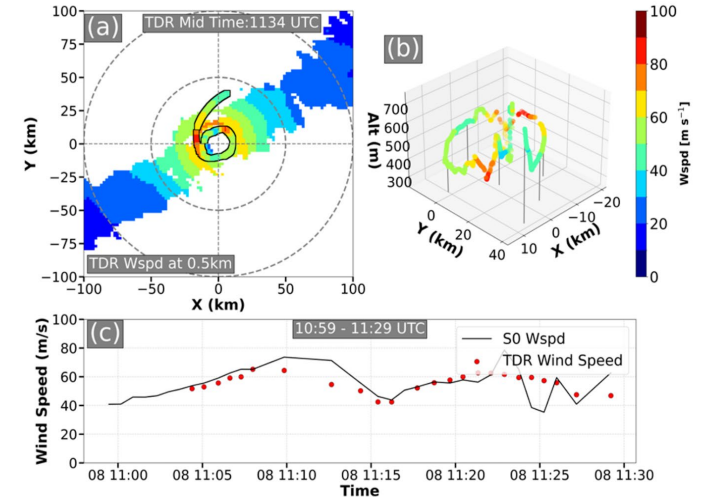
*Courtesy A. Hazelton (CIMAS/HRD)

Research to Operations (R2O)

- Forecast aid development
- Model storm structure evaluation
- Emerging technologies assessment

S0 (sUAS)-TDR Comparison

(Milton 2024)



*Courtesy J. Zhang & G. Lin (CIMAS/HRD)



Science Drivers for Future NOAA Airborne Radar

PRIMARY

Operational Requirement for 3-D Winds

- Flight-track-centered volume
- Across-track coverage ≥ 100 km

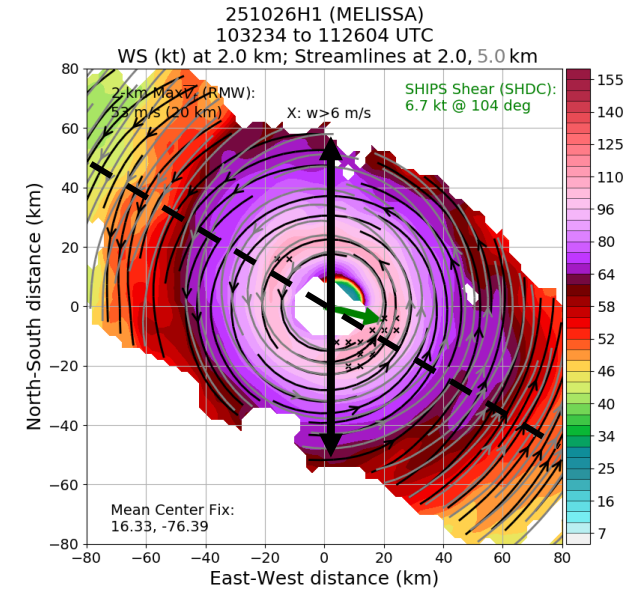
SECONDARY (but important)

Research & R2O

- TC intensity change: Vortex alignment, BL processes
- Model (physics-based & AI) evaluation and development
- Surface wind guidance
- Emerging technologies assessment

Specific Drivers for Future Airborne Radar

- HAFS microphysics development; thermodynamics of TC alignment
- High-resolution, three-dimensional TC BL wind structure



Future Airborne Radar: G550 TDR



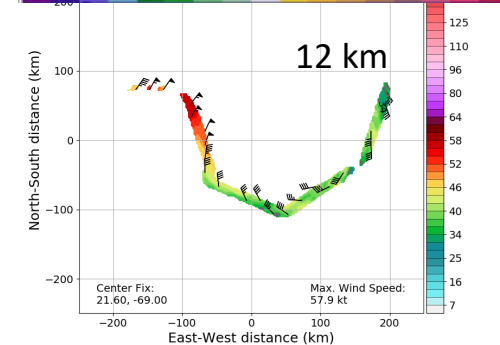
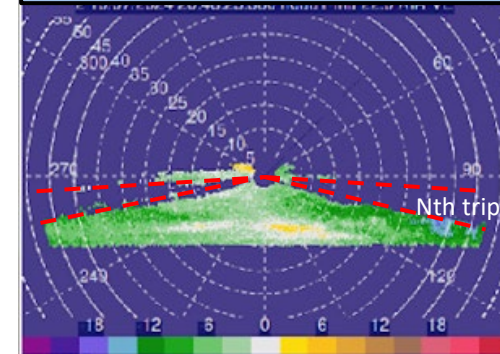
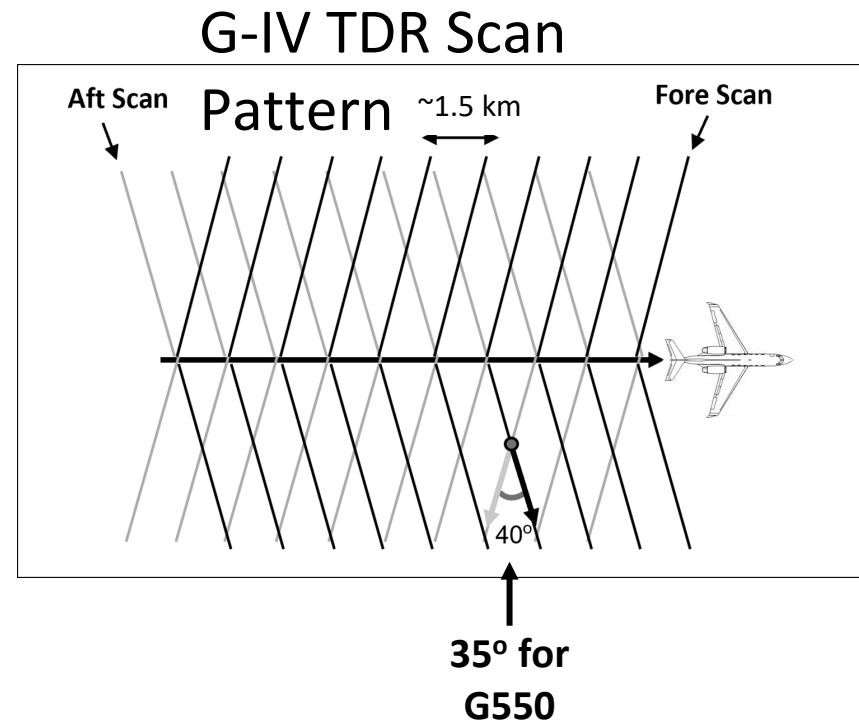
Timeline

- 1st delivery mid-late August
- TDR integration after 1 Oct
- Testing ~early 2027

Important Considerations

- Fore angle reduction: $20^\circ \rightarrow 15^\circ$
- Max alt increase: 45 kft \rightarrow 51 kft
- Speed changes and scan spacing

More effective use of *current* technology?



Future Airborne Radar: C-130J Wing-Pod VSDR

Timeline

- C-130J production later 2026
- 1st delivery summer 2029
- VSDR integration 2029-2030



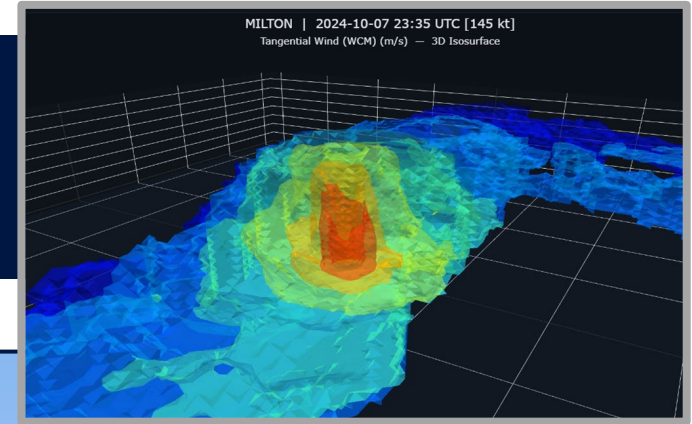
Wing-Pod VSDR Specs

- Flat-plate antenna (x 4), X-Band
- Mechanically-rotated
- Fore & Aft antennas split in pod
- 360° coverage from 2 pods
- Beamwidth: 2° (P-3) → 2.7° (G-IV)
- Located at OWS 330
- Possible: Increased transmit power

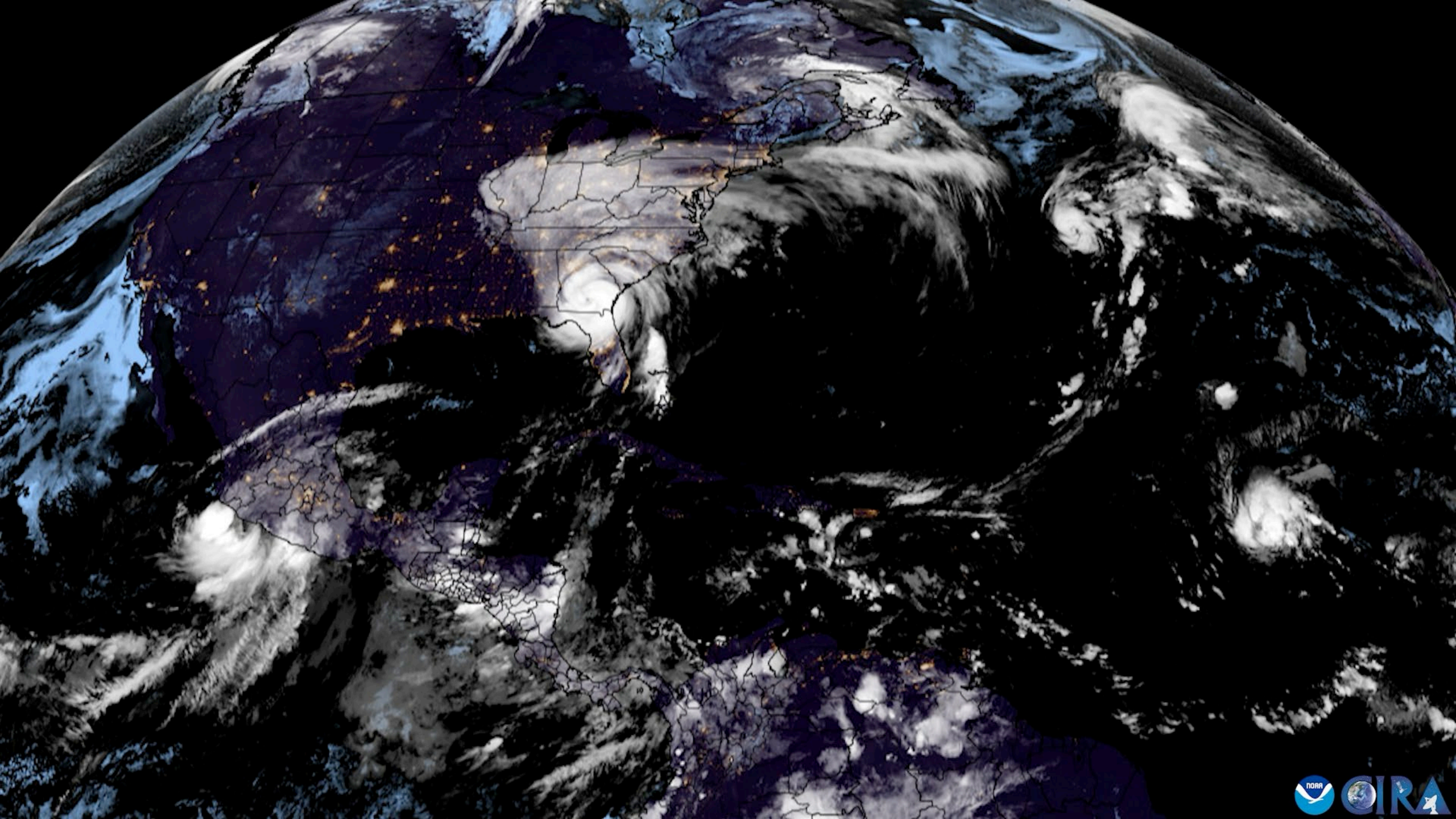
Important Considerations


- Tradeoffs: Beamwidth, Fore/Aft tilt angle
- Wing flexing and propeller vibrations
- Piecing together sweeps for 360° coverage
- TDR software incompatibility w/ C-130J VSDR
- Replacement software transitioned by 2029

NOAA Science Drivers: Key Takeaways

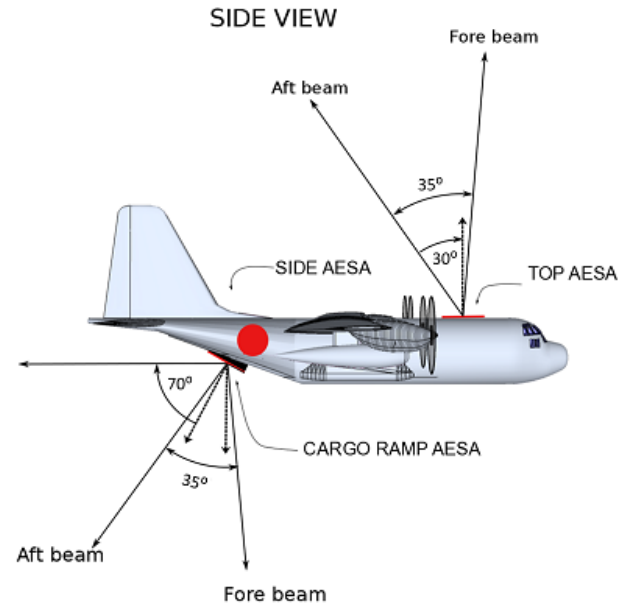


- **Primary science driver: Operational requirement for 3-D wind volumes**
- **Platform, technology maturity & operational timeline considerations governed NOAA Science response to the C-130J VSDR Analysis of Alternatives**
- **After addressing NOAA's primary science driver in 2030:**
 - C-130J Plan includes phased array panel integration targeting research science drivers
 - Discuss optimal placement to address science drivers



- 
- A satellite view of Earth showing the Americas and surrounding oceans. The image is overlaid with a white text box containing two bullet points. In the bottom right corner, there are logos for NOAA and OIRA.
- Over 2/3 of our planet is oceanic
 - Oceanic storms and clouds play a critical role in global weather and climate

Unique platforms and instruments required

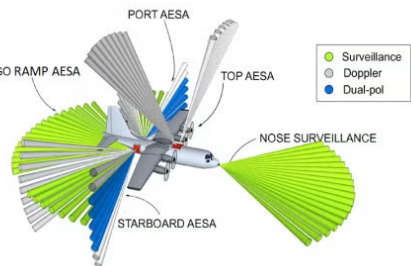


**NSF NCAR Airborne
Phased Array Radar
Concept Diagram**

- ***Niche market but not niche science***
- Years of effort to design and build instrument, plan and conduct field experiment, quality control the data, then analyze and publish results.
- Much smaller volume than operational and ground-based data, but unique and important data to reduce uncertainties and solve scientific problems

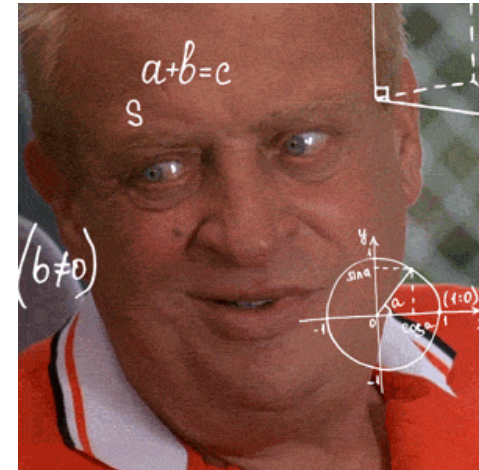
Shipborne and airborne radar data can help reduce uncertainty at observation, state, and process levels

Better data at multiple space and time scales in remote locations



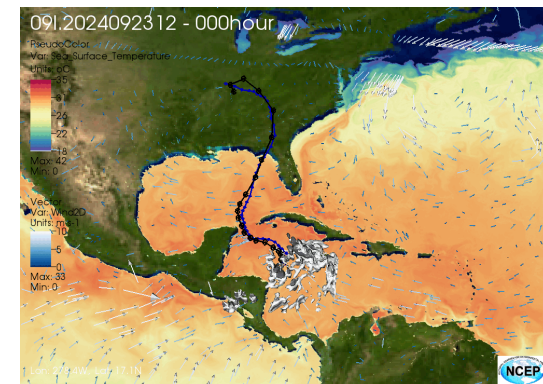
Reduced Observational Uncertainty

Better conceptual models



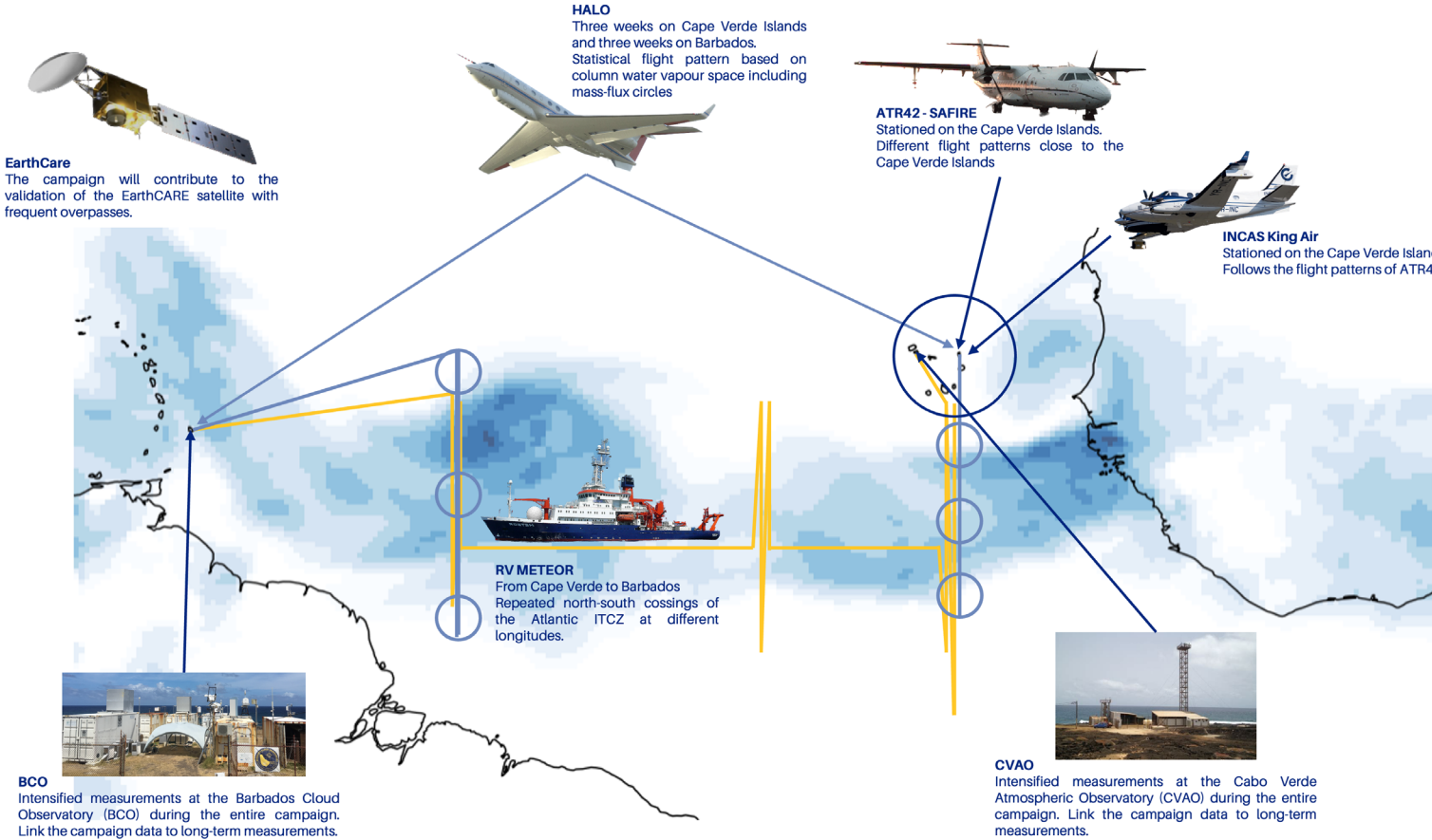
Reduced State Uncertainty

Reduced Process Uncertainty



Better numerical and data-driven models

ORCESTRA : ORganized Convection and EarthCare Studies over the TRopical Atlantic



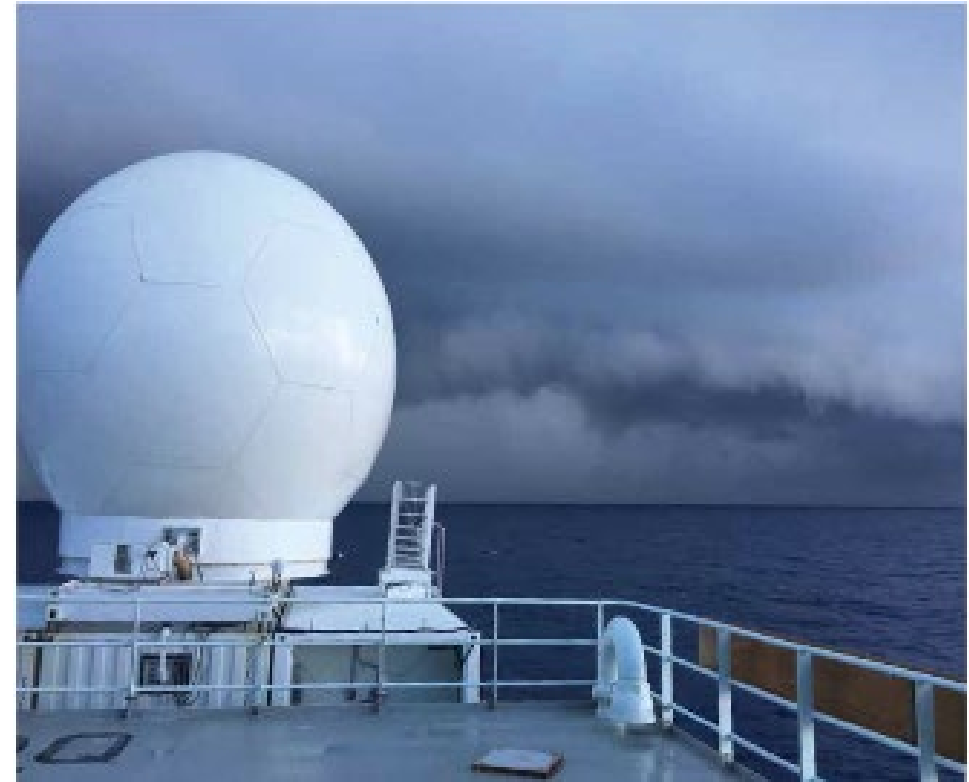
- Each platform has strengths and weaknesses
- First stabilized polarimetric ship radar in eastern Atlantic since GATE 1975

Overarching objective:

Better understand physical mechanisms that organize tropical convection at the mesoscale, and the impact of convective organization on climate and Earth's radiation budget

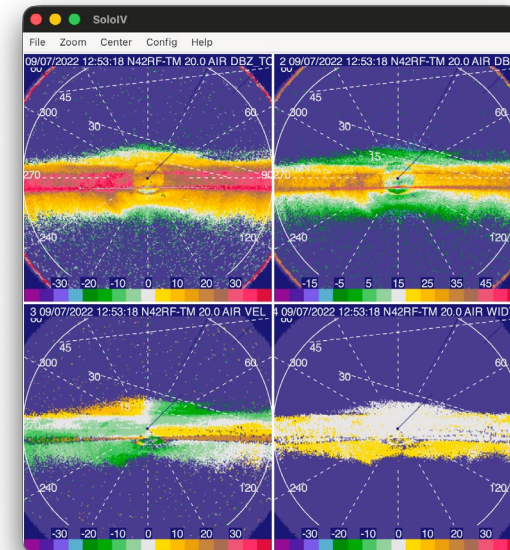
Opportunities And Challenges With Ship And Airborne Data

- **Take the radar to the storm!**
 - Adds additional constraints on size, weight, and sampling requirements
- **Mobility adds challenges to pointing angle determination, velocity recovery, and polarimetry**
 - Ideally scan rate \gg platform motion
- **Ship or airborne radar requires a platform that requires extra costs, maintenance, and request process**



Discussion Points

- **We need ship and airborne platforms with the same capabilities as their ground-based counterparts**
 - Size, weight, and scan rate involve trade-offs, but **polarimetry should be standard** on modern radars
- **Software advancements are just as important as hardware**
 - Adaptive scanning, better analysis tools, and better open-source workflows can enhance existing and future hardware
 - AI coding will help (<https://github.com/mmbell/soloiv>)



Key Takeaways

- **Ships and planes go where no other radar can, especially over the ocean where observations are lacking**
 - Ship and airborne radars are the only way to get crucial data in remote regions
- **Time and space scales of state and process uncertainty require reduce observational uncertainty on those same scales**
 - Research, operations, NWP, and data-driven models all need close range radar observations that can only be obtained through flights or cruises
- **Trusted software workflows for mobile platform radars are essential for optimal data collection and analysis**
 - Ship and airborne radar data requires special processing, and software requires ongoing resources for development, maintenance, and support.
 - Sparrow.jl (Ship, Plane, and Anchored Radar Research and Operational Workflow) now available at <https://github.com/csu-tropical/Sparrow.jl>



Colorado
State
University



Thank you!

Paul Reasor

NOAA AOML/HRD

Paul.Reasor@noaa.gov

Michael M. Bell

Colorado State University

mmbell@colostate.edu