Science Measurement Gaps: Tropical Cyclones

2026 NSF NCAR Radar Tech. Community Workshop

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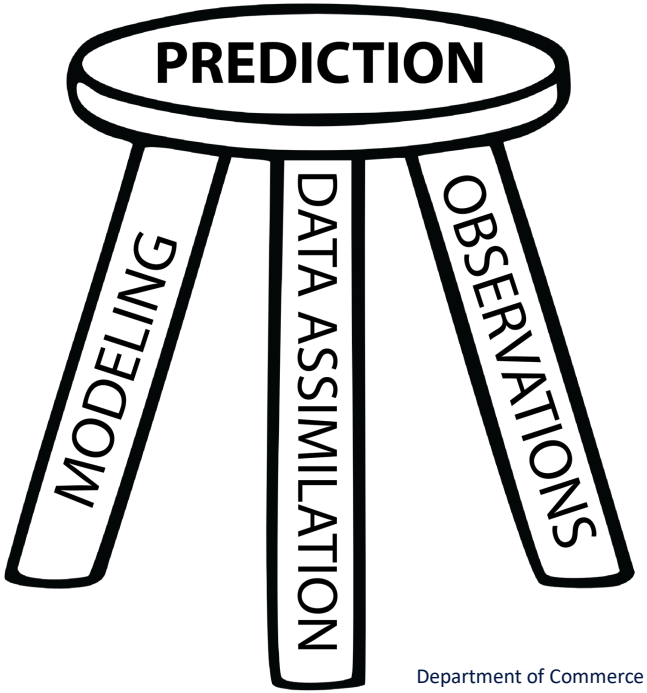
OAR/AOML/Hurricane Research Division
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

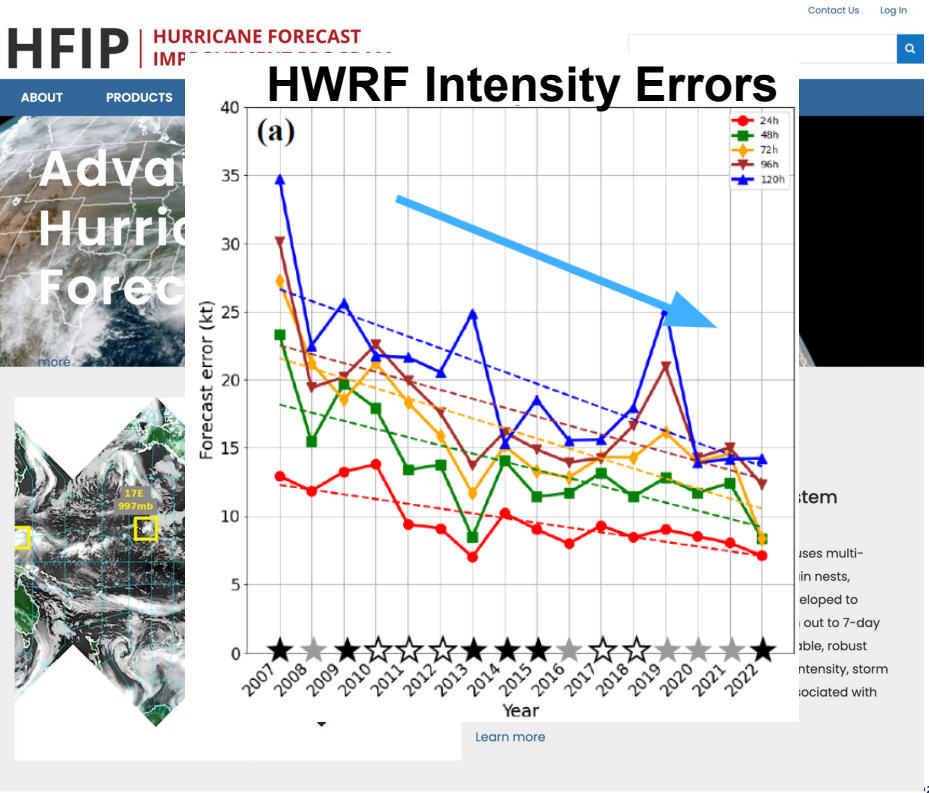
HRD's Mission: Improve Tropical Cyclone Forecasting

The "Frank Marks" Stool



HRD will lead the way into the next generation of tropical cyclone research by studying and advancing **observations**, **observing systems**, **data assimilation**, **numerical modeling**, and the **interactions** between these four ***in a way that no other group in the world is equipped to do***.

History of Observation-Based Improvements



- NHC intensity errors began a notable downward trend in the mid-2000s
- The Hurricane Forecast Improvement Program (HFIP) was established in 2007
- HWRF intensity errors exhibited significant improvements (**45-50%**) over its lifetime as NOAA's flagship hurricane model (2007-2022)

NOAA's Hurricane Field Program 101

Advancing the Prediction of Hurricanes Experiment (APHEX): Goals & Partnerships

Goal 1: Collect observations that span the TC life cycle

Goal 2: Develop measurement strategies and technologies

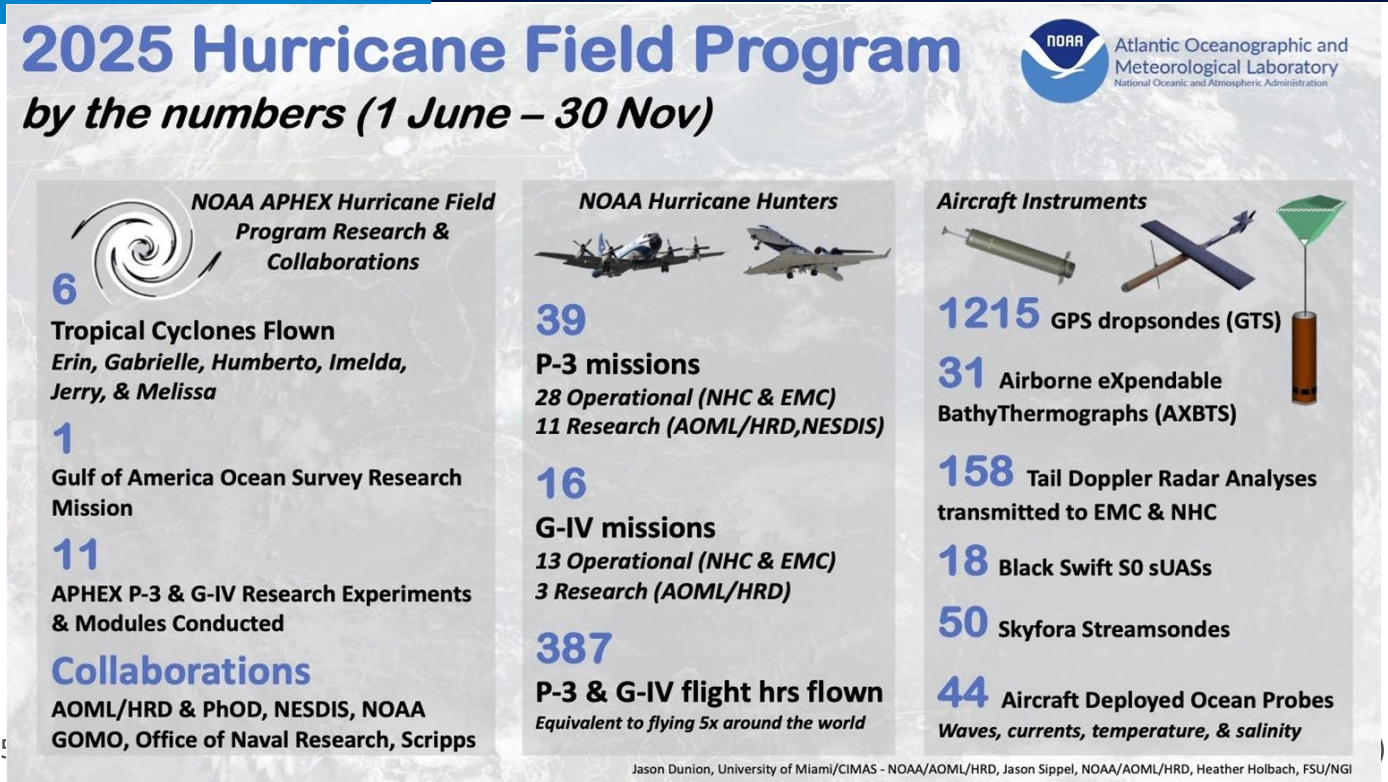
Goal 3: Improve understanding of physical processes

Partnerships: HRD, NHC, EMC, AOC, NESDIS

Collaborations: AOML/PhOD, ONR SASCWATCH, ONR NRL, NASA, NOAA GOMO, Scripps, Stonybrook, Skyfora, Black Swift, UM, CIMAS, NGI

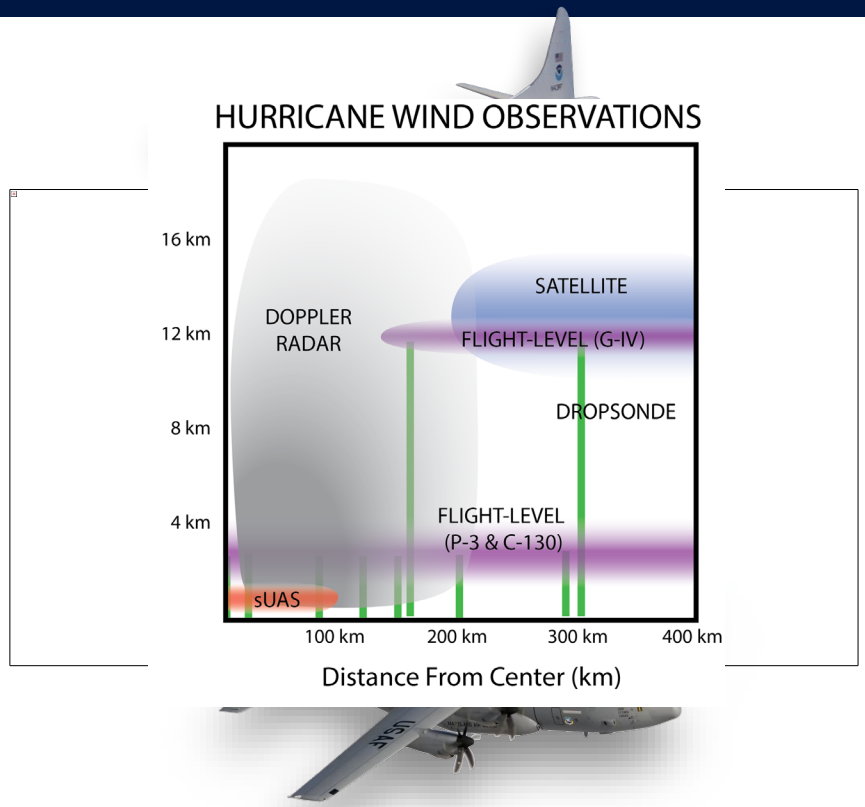
NOAA's Hurricane Field Program 101

*Courtesy of J. Dunion (CIMAS/HRD)



Fleet Transition & Next-Generation VSDR

- P-3/G-IV retirement is imminent. G-550 is online (with TDR).
- Unlike the P-3, the C-130 cannot accommodate a tail radar due to structural/ramp constraints.
- **Analysis of Alternatives (AoA):** NOAA is actively exploring Vertically-Scanning Doppler Radar (VSDR) alternatives, incl. "TDR-like" wing pods.
- **HRD's Focus:** Maintaining high-quality vertical resolution and swath width of the P-3 TDR on a C-130 using wing-mounted pods is an engineering challenge we must solve to avoid a regression in observational capability.
  - Paul will talk more about this tomorrow



Next-Generation Automated VSDR Processing

Collaborators: M. Bell Group (CSU), J. Gamache (HRD), M. Fischer Group (UM)

Phase 1: M-L QC

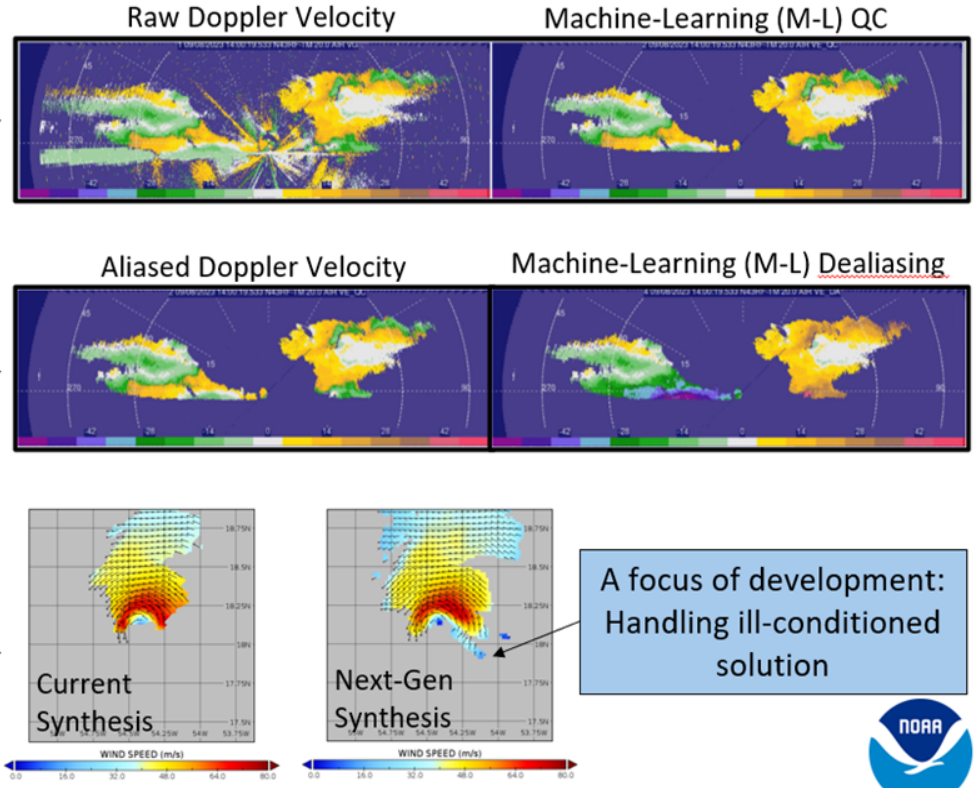
- Easily adaptable to new radars
- Development 2023-25 (WPO)
- P-3/G-IV integration **2026** (RL 8-9)

Phase 2: M-L Dealiasing

- Enables r-t sweep transmission
- Development 2025-27 (WPO)
- P-3/G-IV integration **2028** (RL 8-9)

Phase 3: 3-D Synthesis

- Adaptable to multiple antennas
- Development 2025-27 (WPO)
- P-3/G-IV integration **2028** (RL 8-9)



Science Drivers for Future NOAA Airborne Radar

PRIMARY

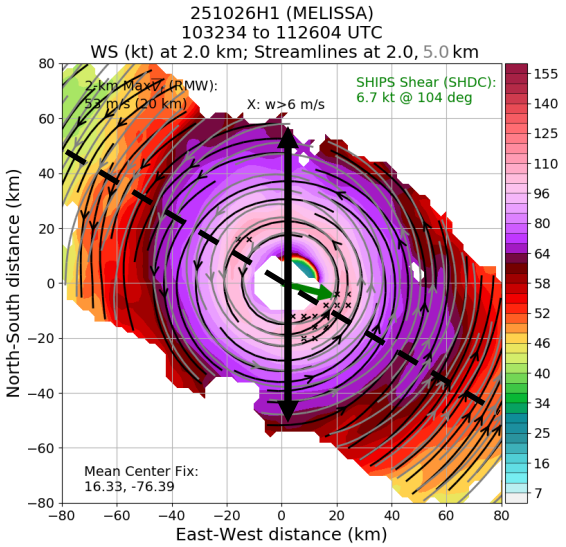
Operational Requirement for 3-D Winds

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

SECONDARY (but

Research & R2O

- TC intensity change: Vortex alignment, BL processes
- Model (physics-based & AI) evaluation and

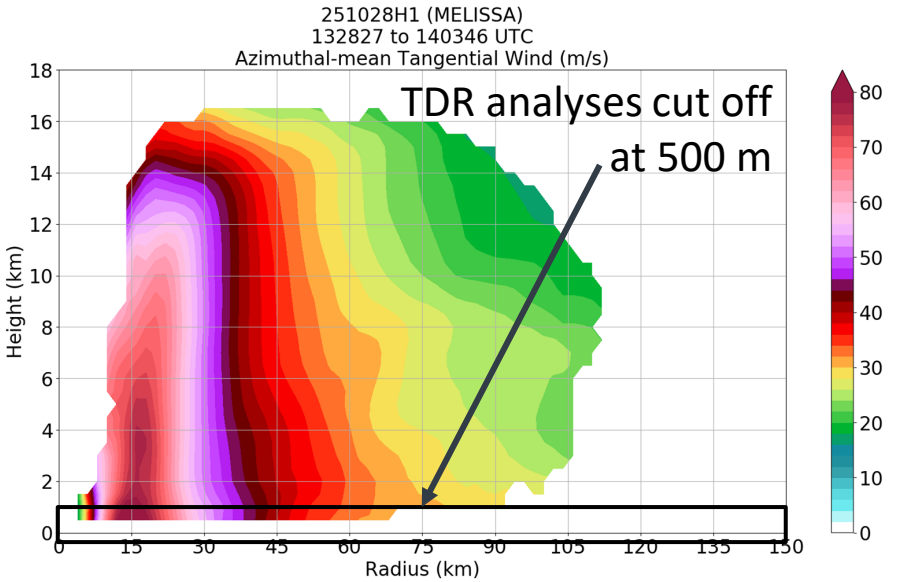


Specific Drivers for Future Airborne Radar

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

Measurement Gaps: *Boundary Layer & Air-Sea Transfer*

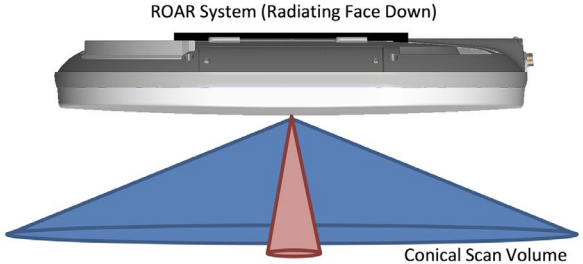
- TC intensity change is governed by enthalpy fluxes in the lowest 200m and corresponding changes to near-surface winds.
- **Gap**: Current radar geometry struggles to cleanly resolve the lowest few hundred meters in high sea states.
- This gap could widen if C-130 has blockage or different scan geometries. We need solutions that peer closer to the surface.



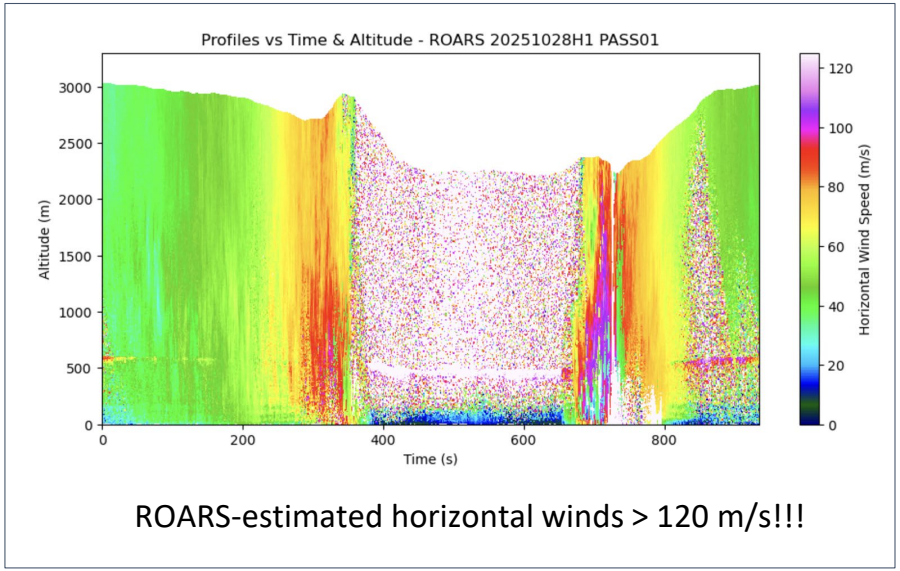
Closing (some) Gaps: *Next-Generation Instruments*

Rain, Ocean and Atmosphere Radar (ROARS)

- An innovative radar system that combines the functionality of a Doppler profiling radar, altimeter and scatterometer into a single compact and robust radar system
- Dual frequency (X-band and Ku-band)



2D electronic scanning within 60 deg cone, Nadir beam shown



ROARS-estimated horizontal winds > 120 m/s!!!

*Courtesy of P. Chang & NESDIS Ocean Winds Team

Closing (some) Gaps: *Data Validation*

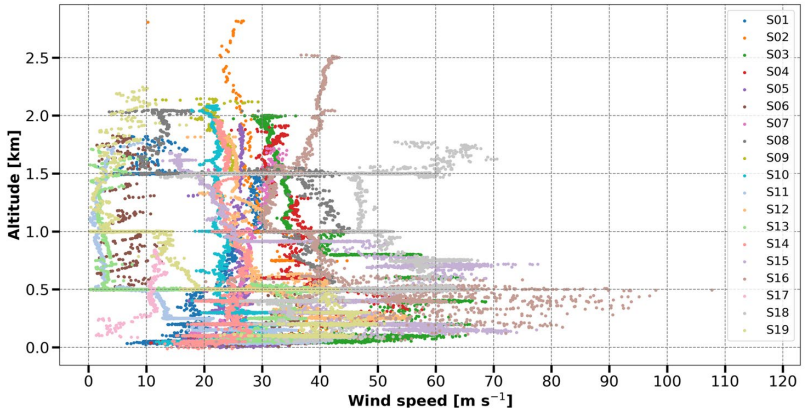
- IWRAP and now ROARS can validate TDR data collected directly below the aircraft
- sUAS (e.g., Black Swift S0) can provide in situ measurements at a specific lat/lon/altitude
    - Ex: Fly the S0 around the eyewall at 500 m (lowest resolvable level from QC-ed TDR)
- Validation works both ways!
- Addresses Boundary Layer

*Courtesy of J. Cione (HRD) and J. Elston (Black Swift)

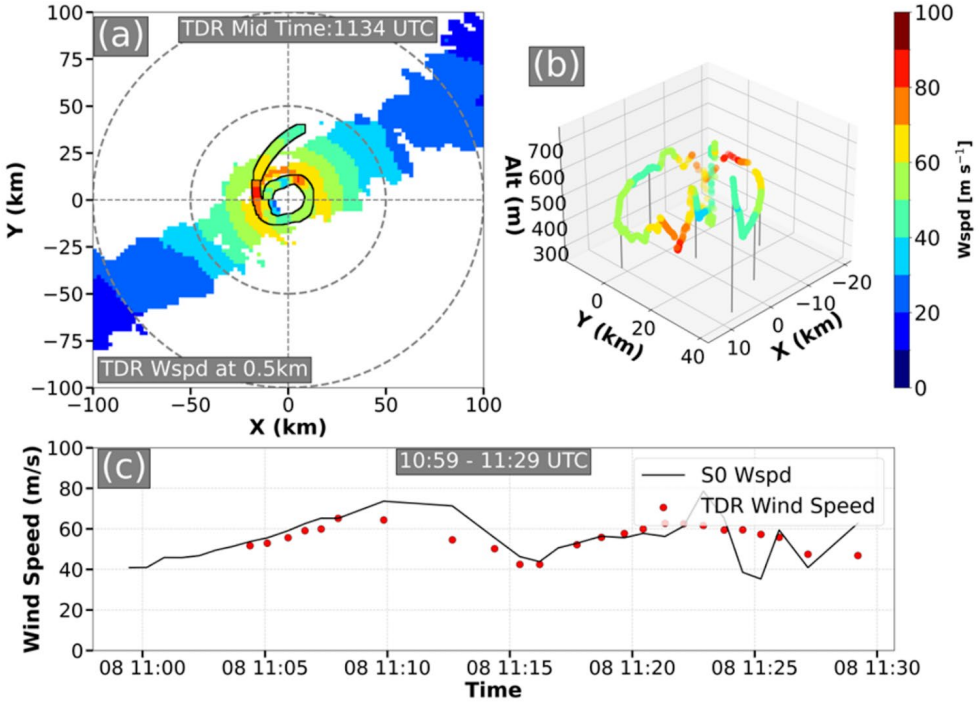
Closing (some) Gaps: *Data Quality Control - S0 vs. TDR*

Milton (2024)

All 19 S0 Deployments into Hurricanes in 2024 (Ernesto, Francine, Helene, Milton)



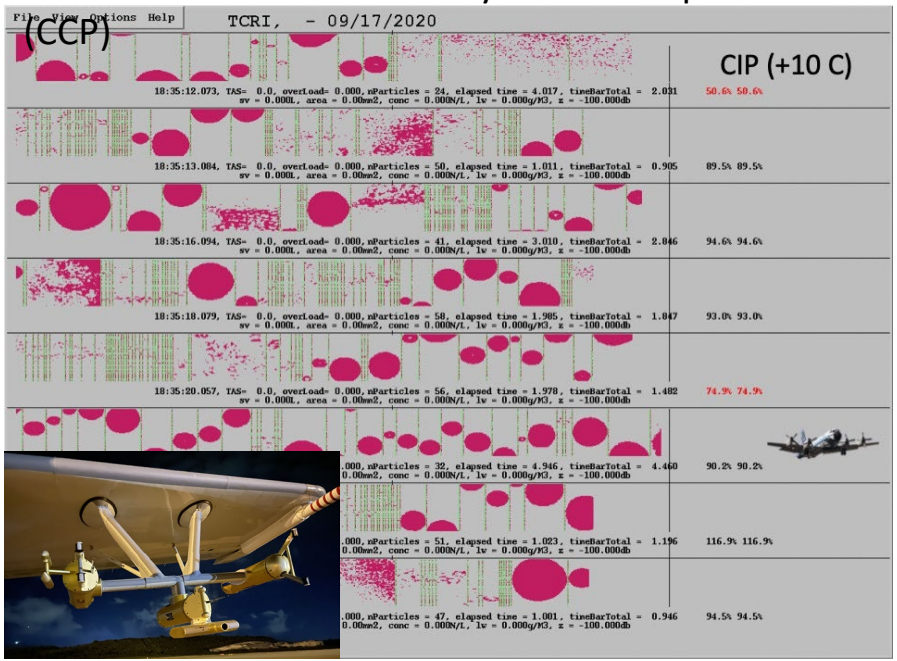
*Courtesy of J. Cione (HRD) and J. Elston (Black Swift)



Measurement Gaps: *Microphysics & Precipitation Structure*

- Latent heating distribution drives vortex intensification, driving a warm core and a vertically-aligned vortex
- **Gap**: We need better characterization of hydrometeor species (ice vs. liquid) to constrain model microphysics.
- As VSDR for C-130 is designed, we must prioritize sensitivity and calibration to ensure we can distinguish hydrometeors for HAFS validation.

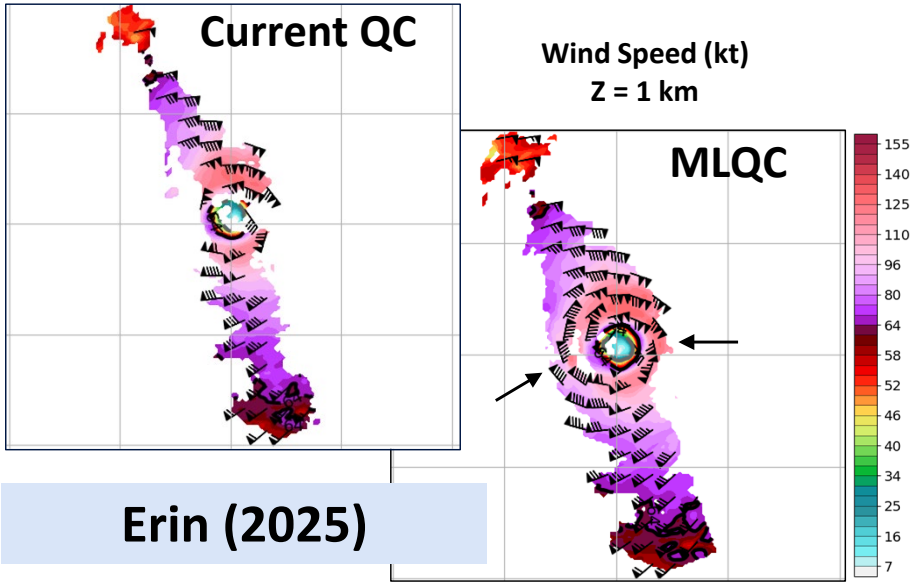
Coordinate radar obs with hydrometeor probe (CCP)



*Courtesy of X. Zhang (HRD)

Closing (some) Gaps: *Increasing TDR Data Impacts*

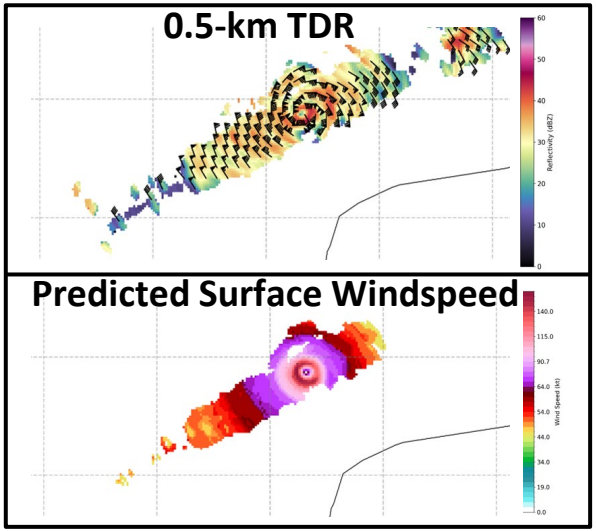
Machine Learning Quality Control



Erin (2025)

AI-Based Surface Wind Reduction

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

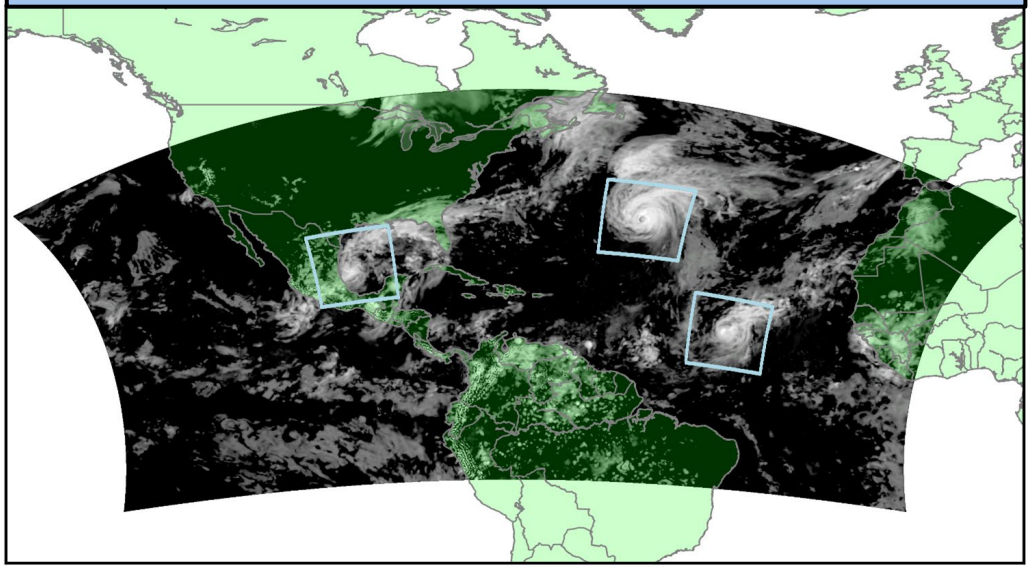


*J.W. Thiesing & M. Fischer (*in prep*)

Enhanced data/guidance for low-level (< 2 km) flow

Hurricane Model R&D: *Hurricane Analysis & Forecast System*

Next-Generation HAFS

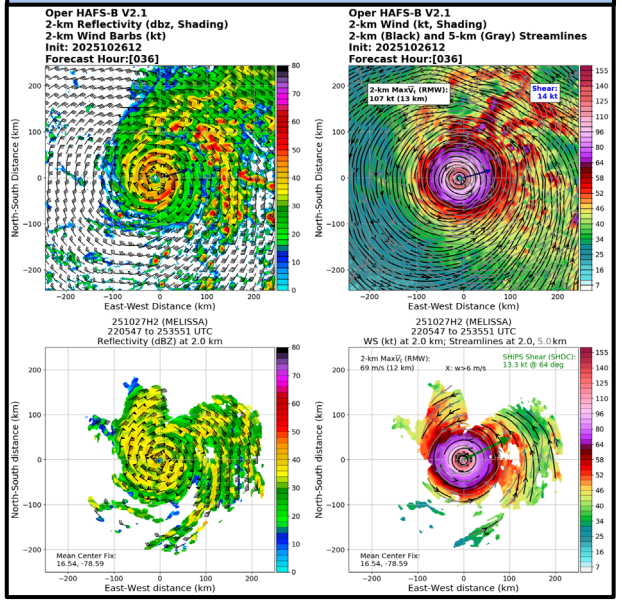


*Courtesy of B. Ramstrom (CIMAS/HRD)

HAFS vs. TDR

HAFS

TDR

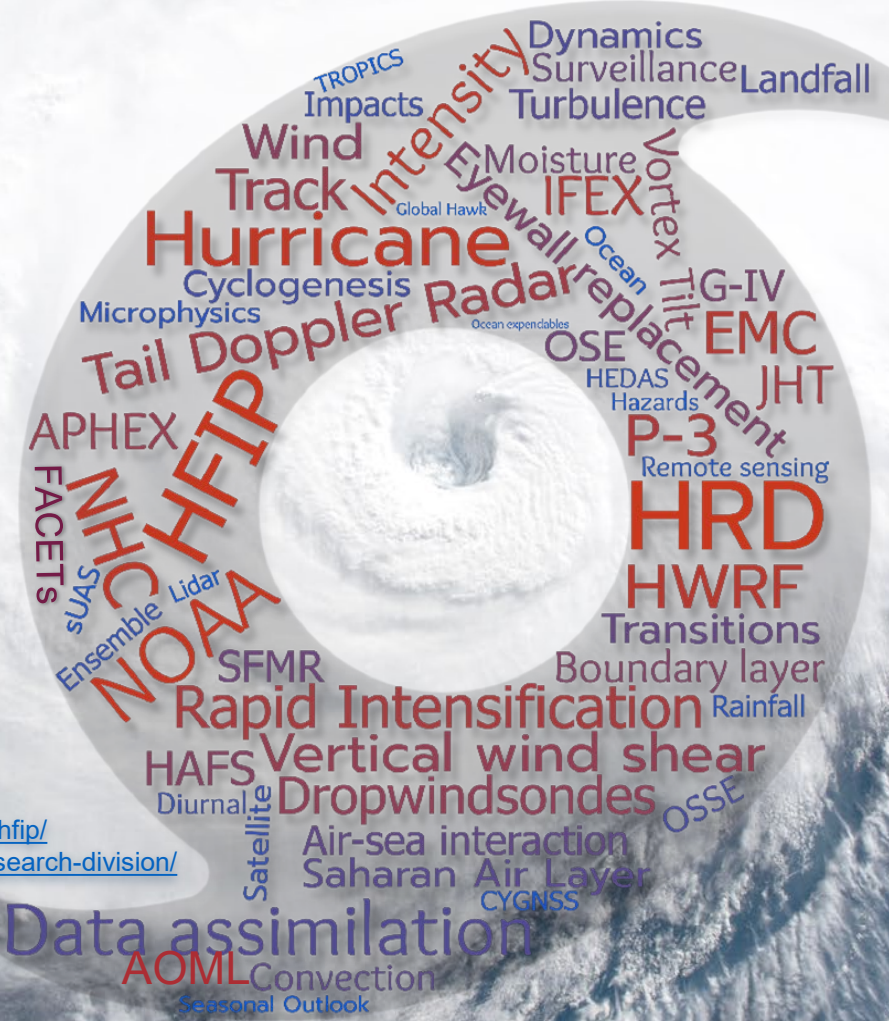


*Courtesy A. Hazelton (CIMAS/HRD)

The Roadmap to 2030 & Beyond

- Transitioning NOAA's fleet without losing data quality is the primary objective.
  - HRD's mission requires this data to be research-quality
- Continued HAFS DA improvements will maximize the value of new radars.
- TDR data impacts
  - > 90% of recon assimilated into HAFS is from TDR
  - Dozens to hundreds of studies that are driving advancements in understanding
- Research and operations requires the continuity of inner-core observations
- The Hurricane Field Program will continue to coordinate the collection of these impactful observations
- **For Radar Engineers**: We need the C-130 solution to mimic the P-3 TDR capabilities as closely as possible (sensitivity, scan rate).
- **For Modelers**: Continue collaborating with HRD to advance impact of radar data on model predictions and to advance its ingestion in current and future DA systems (e.g., HAFS/JEDI)

Questions?



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https://vlab.noaa.gov/web/osti-modeling/hfip/
https://www.aoml.noaa.gov/hurricane-research-division/

History of Observation-Based Improvements

1980s: NCEP begins assimilating dropsondes

2007 HWRF Implementation

2010 2012 2014 2016 2018 2020 2022

2013: HWRF assimilates P3 Doppler velocity

2018: HWRF assimilates all reconnaisance data

2021: GFS assimilates more reconnaissance data

2023 HAFS Implementation

2020: HWRF assimilates NEXRAD data

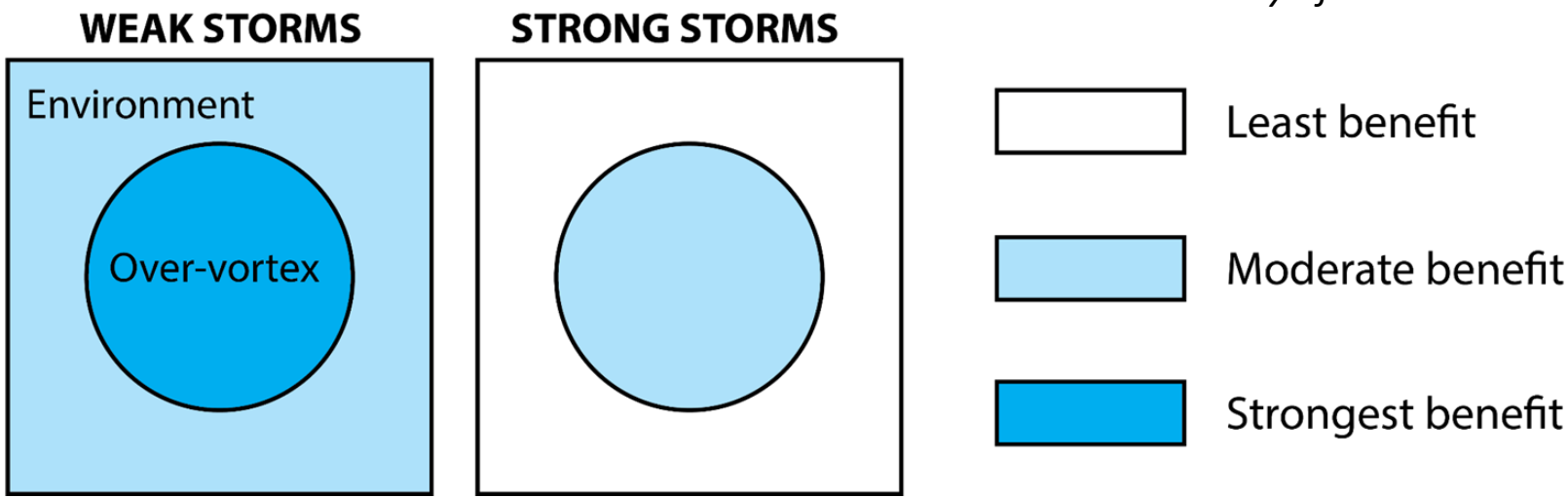
2019: Improved impact of reconnaissance data in HWRF

HRD Contributions to DA at NCEP

- Long HRD backstory back to the 1980s
- 10-20% NWP forecast improvement

Recon Data Impacts: Intensity Forecasts

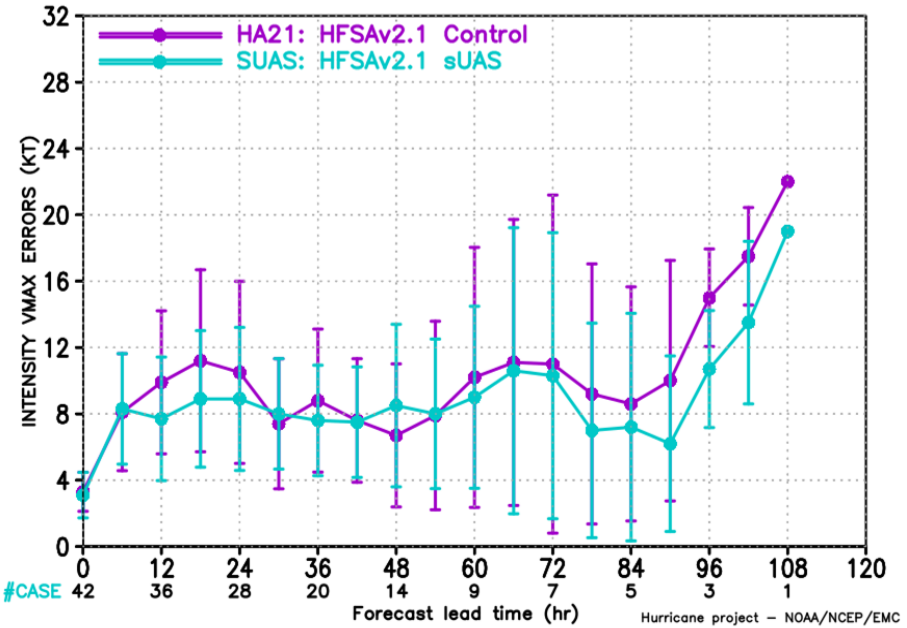
Courtesy of Sarah Ditchek (CIMAS)



Where does reconnaissance benefit intensity NWP the most?

Recon Data Impacts: Emerging Technologies

- Uncrewed systems (UxS) are collecting targeted observations in the most dangerous regions of a hurricane
- *UxS Highlight*: Black Swift S0
  - 3 ft wingspan, ~3 lbs, air-deployed
  - Plan to assimilate S0 data operationally in HAFS in 2026
- Validation of satellite and other remote sensing data



Courtesy of Joe Cione (HRD)