Science in the Sky:

NOAA Aviation from 500’ to FL450

Photos: NOAA, Scott Slocum

Carl Newman

Deputy Director

NOAA Aircraft Operations Center

NOAA Aircraft Operations Center

- NOAA Corps Officers
  - Pilots, Navigators
- Civilians
  - Meteorologists, Technicians, Mechanics, Engineers, Support Staff

Our Home: Lakeland, FL

NOAA Aircraft Operations Center expanding to support growing fleet

City of Lakeland, Florida, will lease additional office and hangar space to NOAA

Marine & Aviation | aircraft operations SHARE

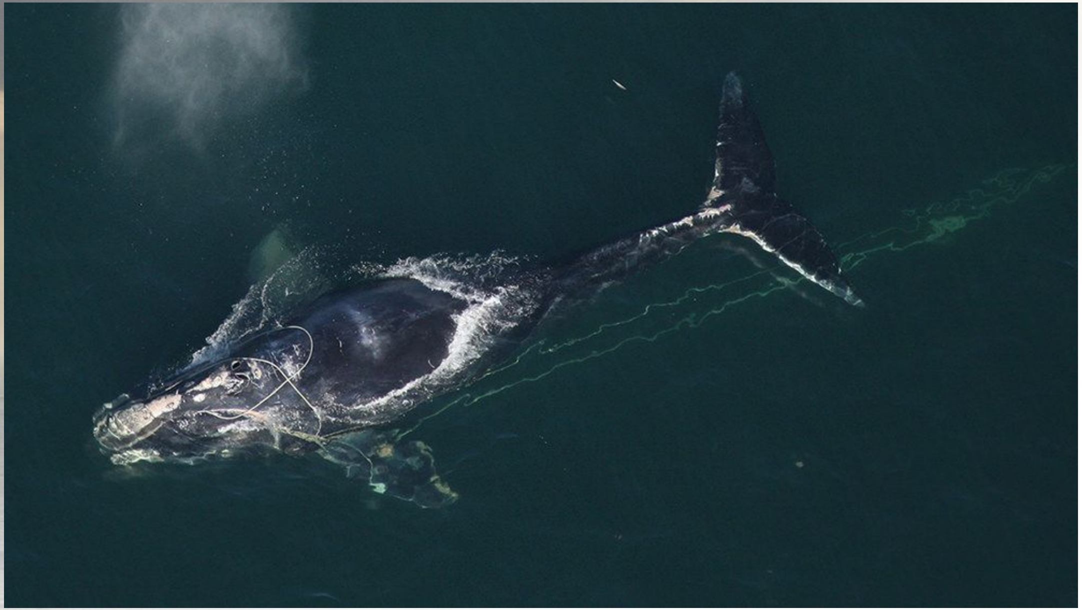
April 16, 2020 — The NOAA Aircraft Operations Center (AOC) will be expanded under the terms of a new 20-year lease NOAA signed today with the City of Lakeland, Florida.

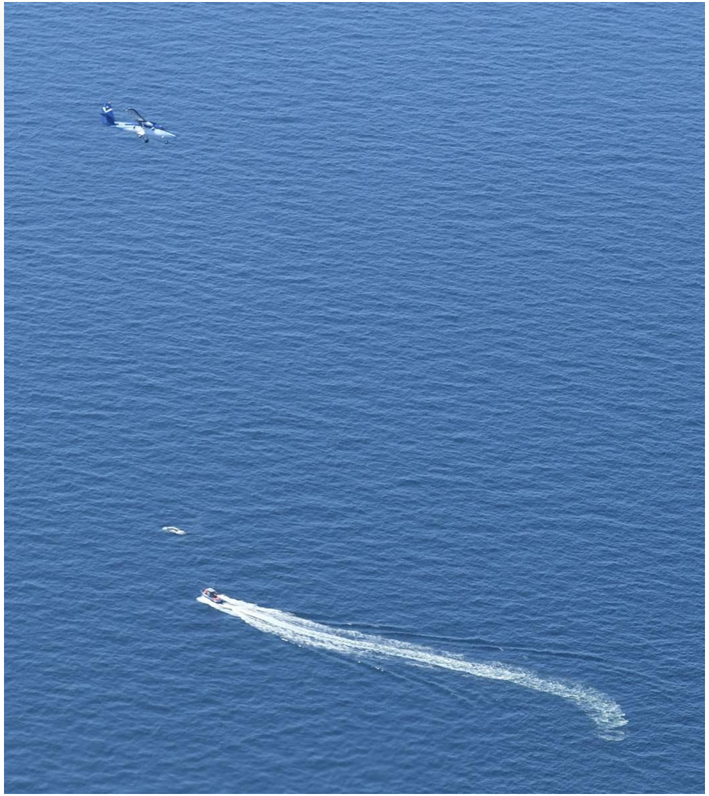
Photos: Lunz Group; NOAA

What Kind of Aircraft Do We Fly?

Photos: NOAA, Jarrod Willkening, Ken Whithers

Focus: Right Whale Surveys





Photos: Entangled Right Whale (NOAA); Twin Otter Disentanglement Effort, Summer 2019

Beechcraft King Air 350CER

- Coastal Mapping & Emergency Response
  - Before storm: Baseline imagery
  - After storm: Post-disaster imagery
- Snow Survey
  - Missions at 500 ft collecting water content of the soil/snow
  - Determines flood forecasts, water supply forecasts when snow melts in the spring

NOAA-68 AOC NGS KING OF THE ROAD

Callsigns: NOAA68, NOAA67

storms.ngs.noaa.gov

Navigation

National Geodetic Survey

Pre-Event Imagery

Contact Us

Content and Technical Issues

Comments and Policy Issues

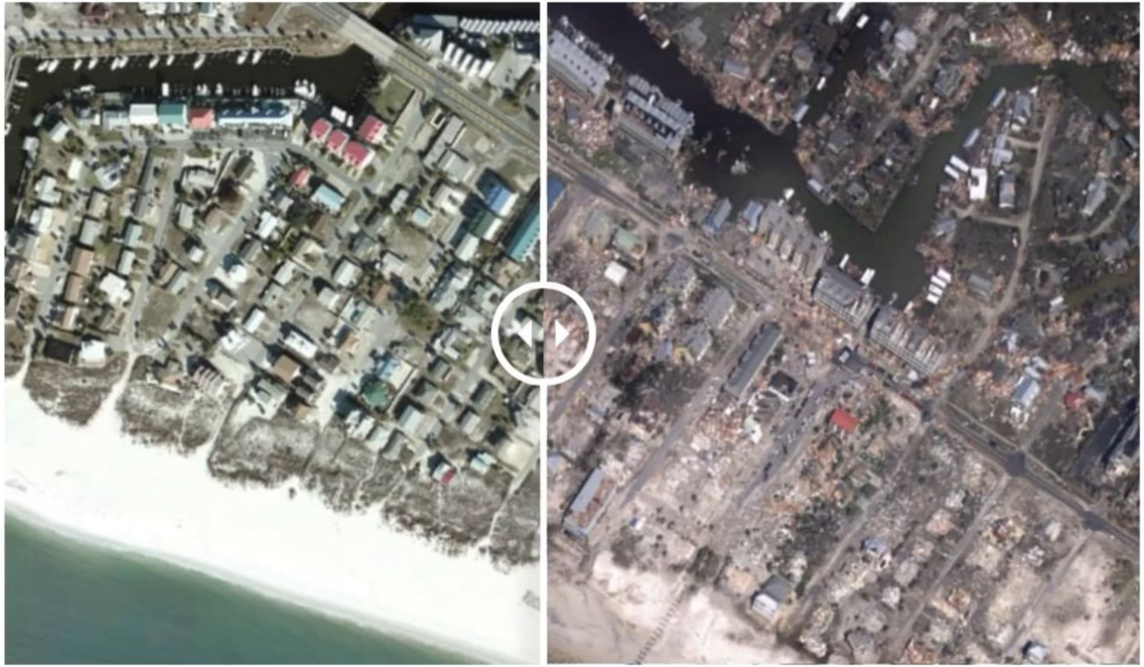
- Louisiana Flooding (2016)
- Midwest U.S. Flooding (2015)
- Illinois Tornadoes (2015)
- Hurricane Arthur (2014)
- Hurricane Sandy (2012)
- Hurricane Isaac (2012)
- Hurricane Irene (2011)
- Joplin, MO Tornado (2011)
- Tuscaloosa, AL Tornado (2011)
- North Dakota Flooding (2011)
- Hurricane Earl (2010)
- Nor'Easter Nov09 (2009)
- Hurricane Ike (2008)
- Hurricane Gustav (2008)
- Hurricane Humberto (2007)
- Tropical Storm Ernesto (2006)
- Hurricane Wilma (2005)
- Hurricane Rita (2005)
- Hurricane Ophelia (2005)
- Hurricane Katrina (2005)
- Hurricane Dennis (2005)
- Hurricane Ivan (2004)
- Hurricane Jeanne (2004)
- Hurricane Isabel (2003)

Coastal Storm Imagery Online in Real Time

Focus: Emergency Response

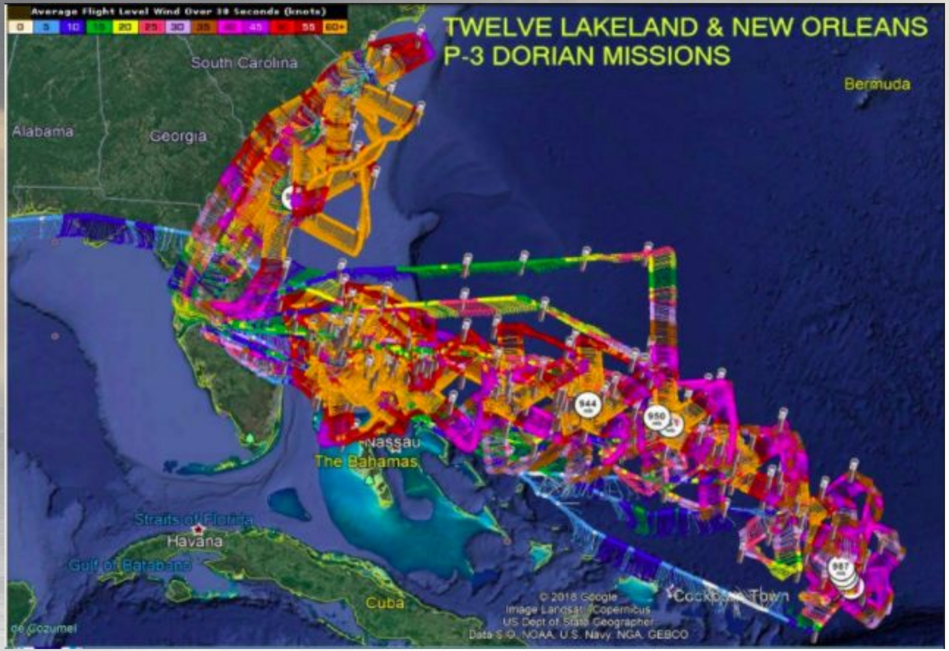
Hurricane Michael

- Aircraft and crew pre-staged to respond
- Near real-time images available



Mexico Beach, Florida | *View this location on the map.*

Why Fly Hurricane Missions?

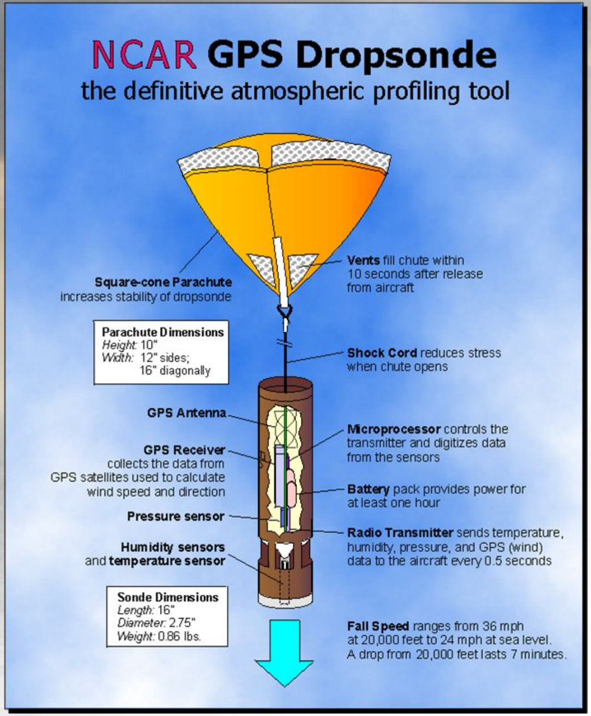


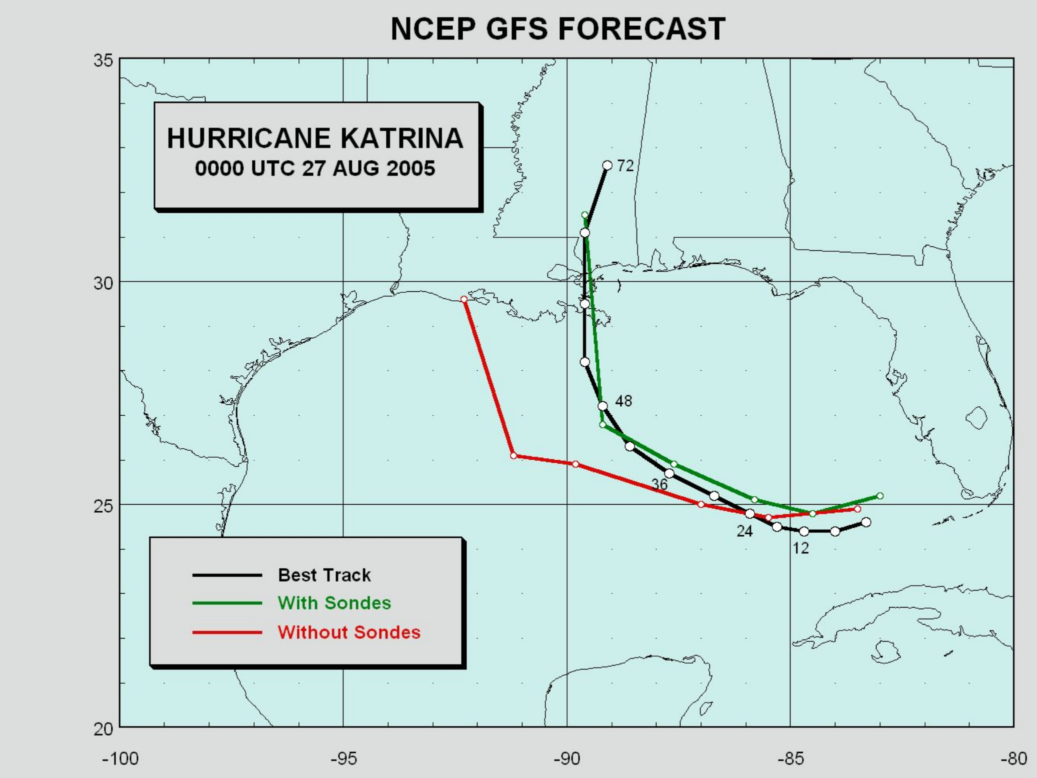
Gulfstream IV-SP

- High altitude hurricane surveillance (45,000’)
- Mission: above and around storm environment to determine hurricane track
- Callsign:
  - NOAA49 aka “Gonzo”

Photos: NOAA

Dropsondes


NCAR GPS Dropsonde
the definitive atmospheric profiling tool
Square-cone Parachute increases stability of dropsonde
Vents fill chute within 10 seconds after release from aircraft
Parachute Dimensions
Height: 10"
Width: 12" sides; 16" diagonally
Shock Cord reduces stress when chute opens
GPS Antenna
Microprocessor controls the transmitter and digitizes data from the sensors
GPS Receiver collects the data from GPS satellites used to calculate wind speed and direction
Battery pack provides power for at least one hour
Pressure sensor
Radio Transmitter sends temperature, humidity, pressure, and GPS (wind) data to the aircraft every 0.5 seconds
Humidity sensors and temperature sensor
Sonde Dimensions
Length: 16"
Diameter: 2.75"
Weight: 0.86 lbs.
Fall Speed ranges from 36 mph at 20,000 feet to 24 mph at sea level. A drop from 20,000 feet lasts 7 minutes.


NCEP GFS FORECAST
HURRICANE KATRINA
0000 UTC 27 AUG 2005
Best Track
With Sondes
Without Sondes
72
48
36
24
12
35
30
25
20
-100
-95
-90
-85
-80

WP-3D Orion

- Hurricane Hunters that fly inside the storm environment
- Gather data on storm intensity
- Callsigns:
  - NOAA42 - “Kermit”
  - NOAA43 - “Miss Piggy”

Photo by Scott Slocum/Aero Media Group

Kermit, Miss Piggy, and Gonzo

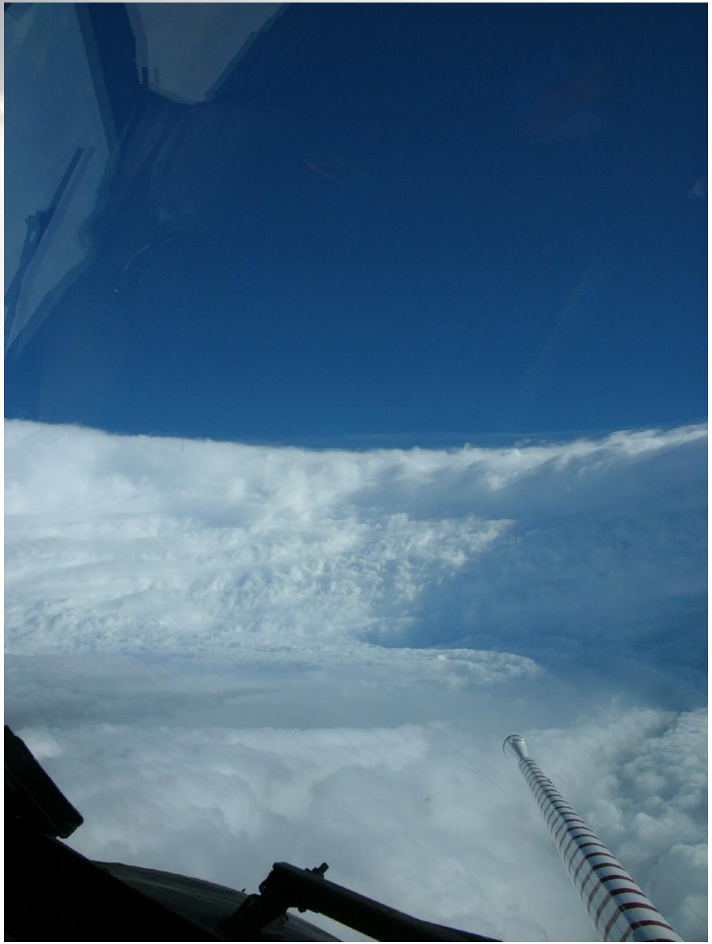
A Flying Laboratory

Hurricane Penetrations

Photo: Nick Underwood, NOAA

“Stadium Effect”

Hurricane Florence, 2018



Hurricane Katrina, 2005

Photos: NOAA

G-IV (left) vs WP-3D (right) Flight Patterns
Hurricane Matthew – October 2016

What Kind of Aircraft Do We Fly?

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION AOC AIRCRAFT OPERATIONS CENTER U.S. DEPARTMENT OF COMMERCE

NOAA HURRICANE HUNTERS

NOAA COMMISSIONED CORPS 1917

Photos: NOAA, Jarrod Willkening, Ken Whithers

More Than Hurricanes

- Year-Round Light Aircraft Missions
- WP-3D:
  - Tornado/Supercell Research
  - North Atlantic Winter Storms
- G-IV:
  - Atmospheric Rivers

Photos: NOAA/ Seattle Times

Questions?

Website:
https://www.omao.noaa.gov/learn/aircraft-operations

Social Media:

- Facebook: The NOAA Hurricane Hunters
- Twitter: @NOAA_HurrHunter
- Instagram: @FlyNOAA

Photo: Jeff Milstein

NHC Usage of Aircraft Data for Tropical Cyclone Analysis

Brad Reinhart
Dr. Lisa Bucci
NHC Hurricane Specialist Unit

NATIONAL HURRICANE CENTER
MIAMI, FL

Hurricane Hunters

HURRICANE HUNTERS
53D WEATHER RECONNAISSANCE SQ

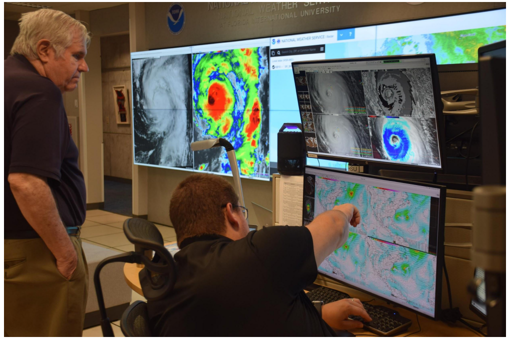
U.S. Air Force
Biloxi, Mississippi

NOAA
HURRICANE HUNTERS

NOAA
Lakeland, Florida

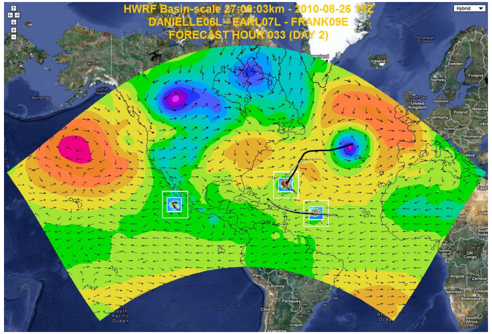
How is aircraft data used?

Analysis
Forecasters



National Hurricane Center

Forecast
Weather Models



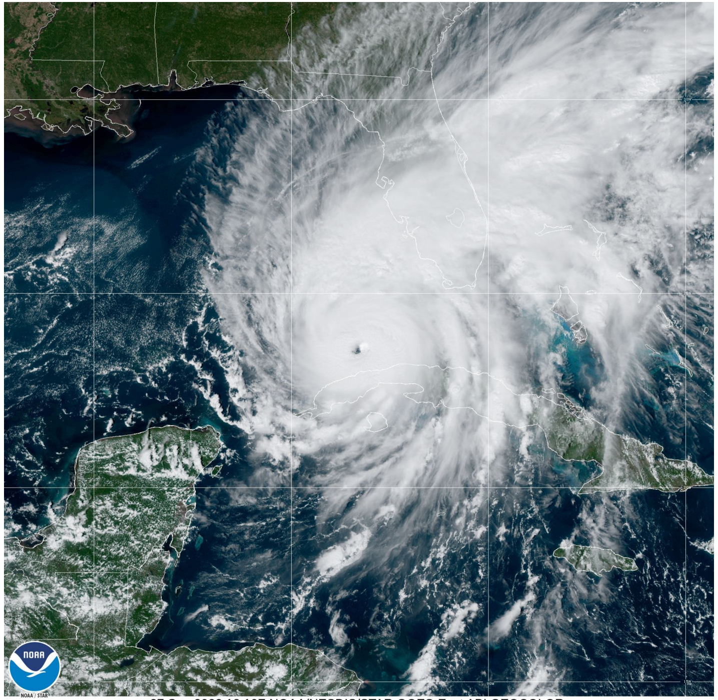
Environmental Modeling Center

Research
Scientists

Hurricane Research Division
Academia & Public (U.S./Intl)

Tropical Cyclone (TC) Analysis

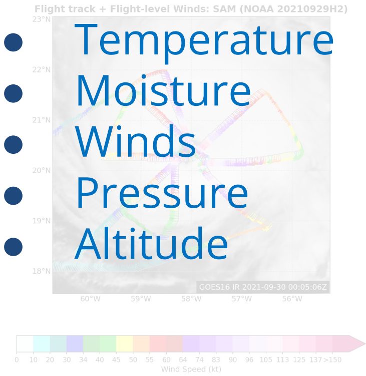
What does a specialist need to determine?


27 Sep 2022 18:10Z NOAA/NESDIS/STAR GOES-East ABI GEOCOLOR

- Center location
- Intensity
  - Peak 1-minute, 10-meter wind speed that is representative of the TC circulation
- Minimum central pressure
- Radius of maximum wind
- Wind radii
  - Maximum extent of 34-, 50-, and 64-kt winds in each quadrant of the TC

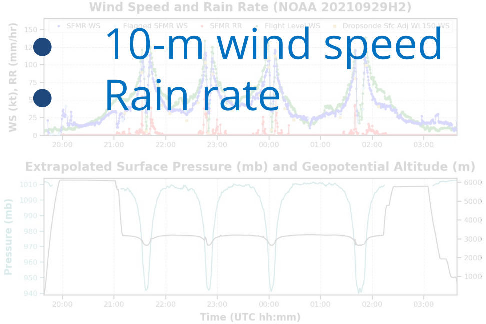
Aircraft Data

Aircraft probes



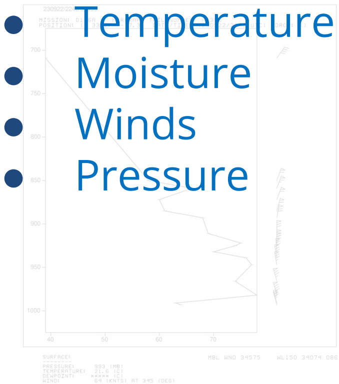
- Temperature
- Moisture
- Winds
- Pressure
- Altitude

Stepped Frequency Microwave Radiometer (SFMR)



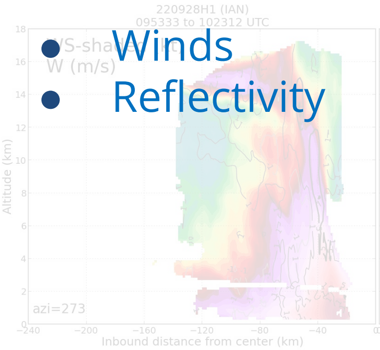
- 10-m wind speed
- Rain rate

Dropsondes



- Temperature
- Moisture
- Winds
- Pressure

X-band Doppler radar (NOAA)



- Winds
- Reflectivity

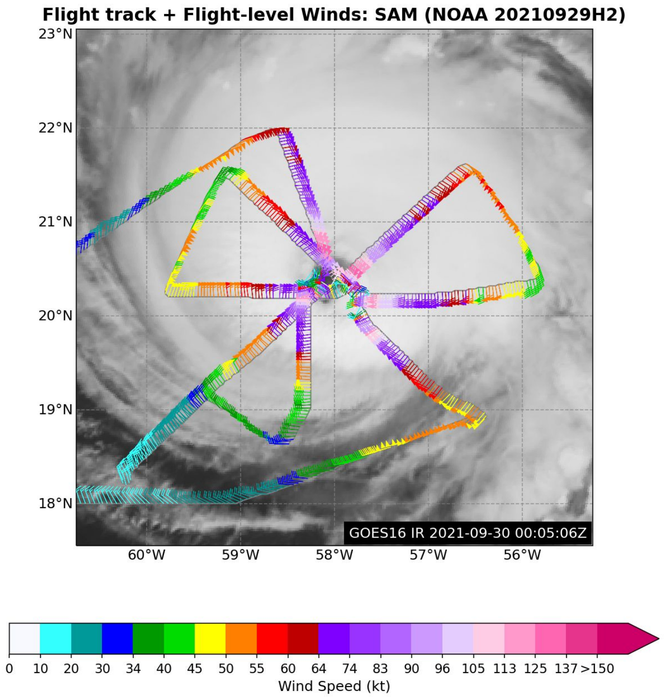
Flight-Level Winds

Strengths

- Frequent, accurate wind speed observations along the flight track

Limitations

- Representativeness (only at one level)
- Wind speeds require an adjustment from flight-level to estimate the surface winds



Flight-Level Winds

- Based on past research, flight-level winds are adjusted using standard reduction factors to estimate surface wind speeds
- Reduction factors differ depending on the flight level of the aircraft and the storm environment being sampled

Flight Level	Eyewall	Outer Vortex (convection)	Outer Vortex (not in convection)
700 mb	0.90	0.85	0.80
850 mb	0.80	0.80	0.75
925 mb	0.75	0.75	0.75

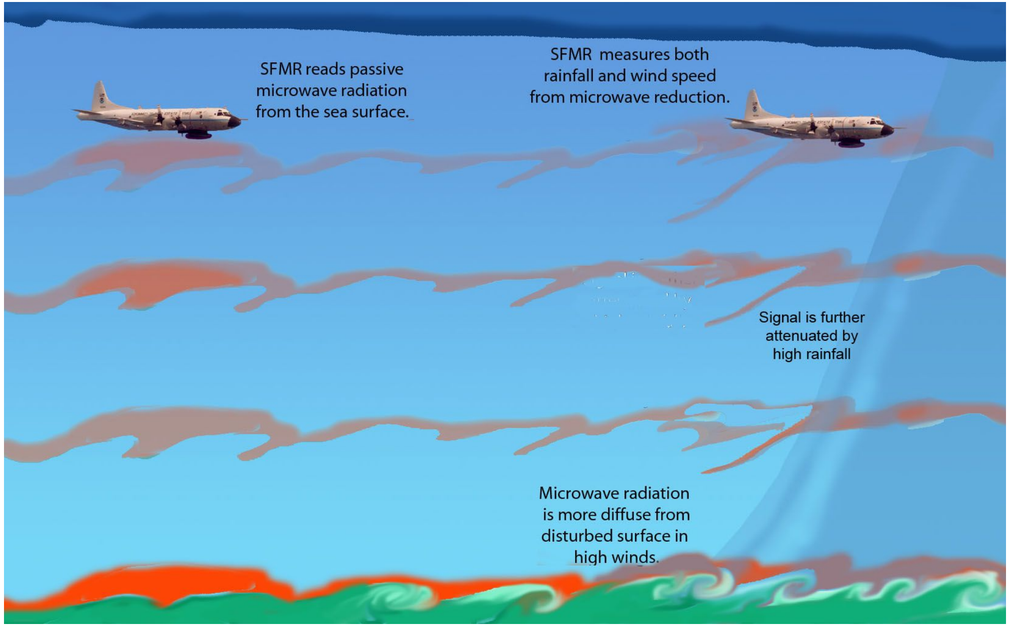
Adapted from Franklin et al. (2003)

SFMR Winds

Stepped Frequency Microwave Radiometer

- SFMR measures microwave radiation from the sea surface.

- The measured microwave emission is a function of (among other things) the surface wind speed and the rain rate.



NOAA/AOML

SFMR Winds

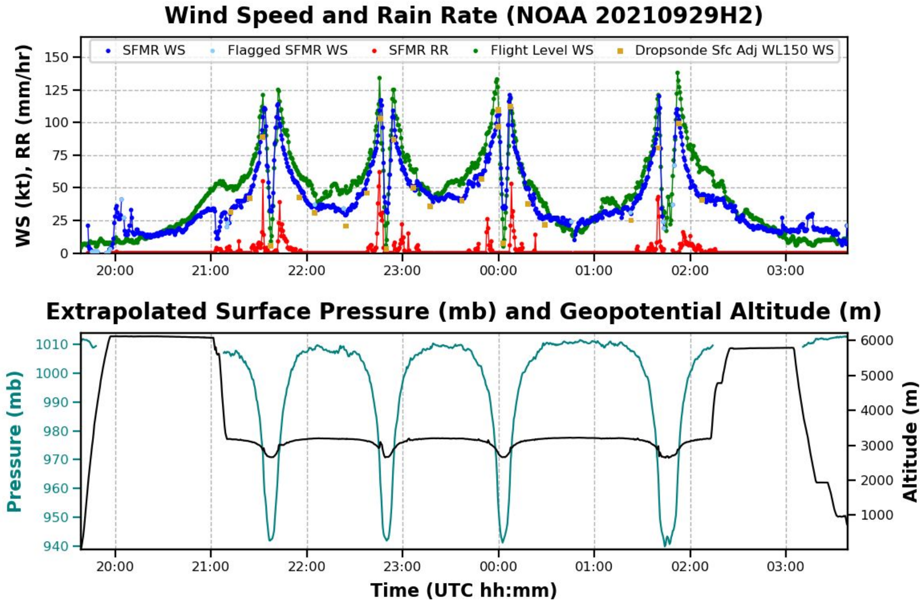
Stepped Frequency Microwave Radiometer

Strengths

- Derived surface wind speed
- Helps assess peak intensity and storm size parameters

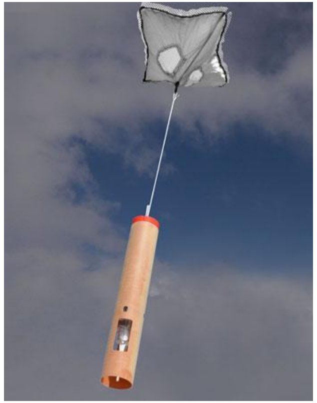
Limitations

- Potential calibration issues at extreme wind speeds
- Overestimates winds in shallow water
- ?? data in high rain rates



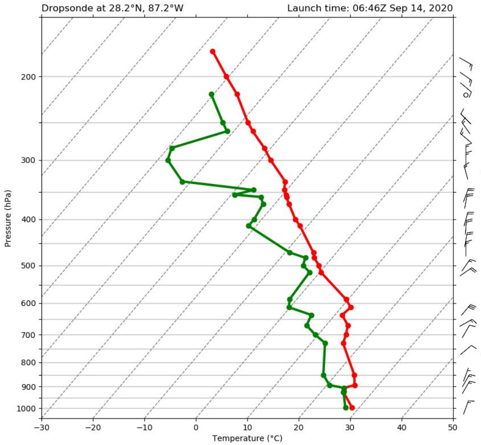
Dropsondes

- Expendable device dropped from an aircraft that collects temperature, wind, and moisture data as it falls



Strengths

- Provides accurate and frequent measurements in a profile throughout the atmosphere
- Helps assess vertical structure, winds, and minimum pressure



Level	Height	Temp	RH	Wind
200 mb	12510 m	-50.5 °C	N/A	SE at 14 kt
250 mb	11020 m	-38.7 °C	60%	NW at 11 kt
300 mb	9740 m	-28.1 °C	13%	N at 16 kt
400 mb	7610 m	-13.5 °C	51%	NNE at 19 kt
500 mb	5870 m	-1.3 °C	79%	NE at 17 kt
700 mb	3086 m	15.4 °C	67%	NE at 10 kt
850 mb	1411 m	23.6 °C	69%	NNE at 7 kt
925 mb	666 m	24.4 °C	100%	NNE at 15 kt
997 mb	0 m	28.6 °C	93%	NNE at 17 kt

Table 1. Mandatory Level Data

Level	Wind
700 mb	NE at 10 kt
754 mb	NE at 10 kt
850 mb	NNE at 7 kt
875 mb	NNE at 14 kt
894 mb	NNE at 12 kt
904 mb	NNE at 17 kt
925 mb	NNE at 15 kt
997 mb (surface)	NNE at 17 kt

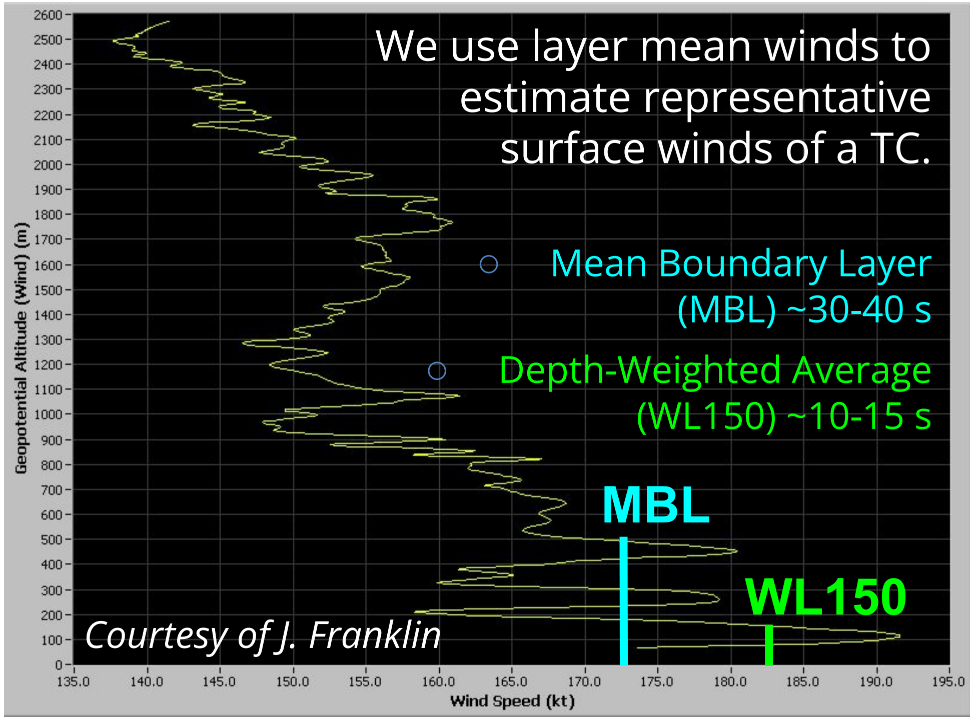
Table 2. Significant Wind Data Below 700 mb

Drop Location in Storm: Unknown
Mean Wind in Lowest 500 m: NNE at 16 kt
Mean Wind in Lowest 150 m: NNE at 17 kt
Max Wind in Sounding: N/A

Dropsondes

Limitations

- Point observation/ representativeness
- Dropsonde may drift or be advected away from the area where it was released
- The surface winds are generally not representative of a 1-min sustained wind



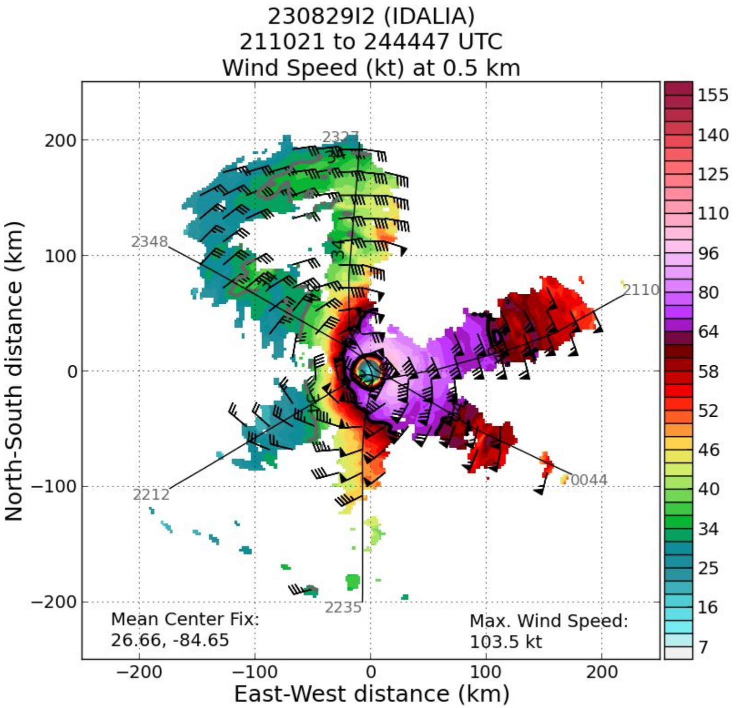
Tail Doppler Radar (TDR)

Strengths

- Provides a 3-D view of the TC wind and precipitation structure
- Helps assess real-time structural and size changes

Limitations

- Only onboard NOAA aircraft
- Does not provide surface wind data (lowest scan at 0.5 km)



Vortex Data Message (VDM)

VORTEX DATA MESSAGE AL182021
A. 29/22:49:29Z
B. 20.23 deg N 057.91 deg W
C. 700 MB 2602 m
D. 943 mb
E. 130 deg 10 kt
F. CLOSED
G. C26
H. 117 kt
I. 260 deg 14 nm 22:46:11Z
J. 001 deg 134 kt
K. 262 deg 17 nm 22:45:31Z
L. 109 kt
M. 086 deg 18 nm 22:53:50Z
N. 179 deg 125 kt
O. 086 deg 19 nm 22:54:09Z
P. 9 C / 3066 m
Q. 16 C / 3072 m
R. 9 C / NA
S. 1234 / 7
T. 0.01 / 1 nm
U. NOAA2 1218A SAM OB 15
MAX FL WIND 134 KT 262 / 17 NM 22:45:31Z
MAX FL TEMP 17 C 084 / 13 NM FROM FL CNTR

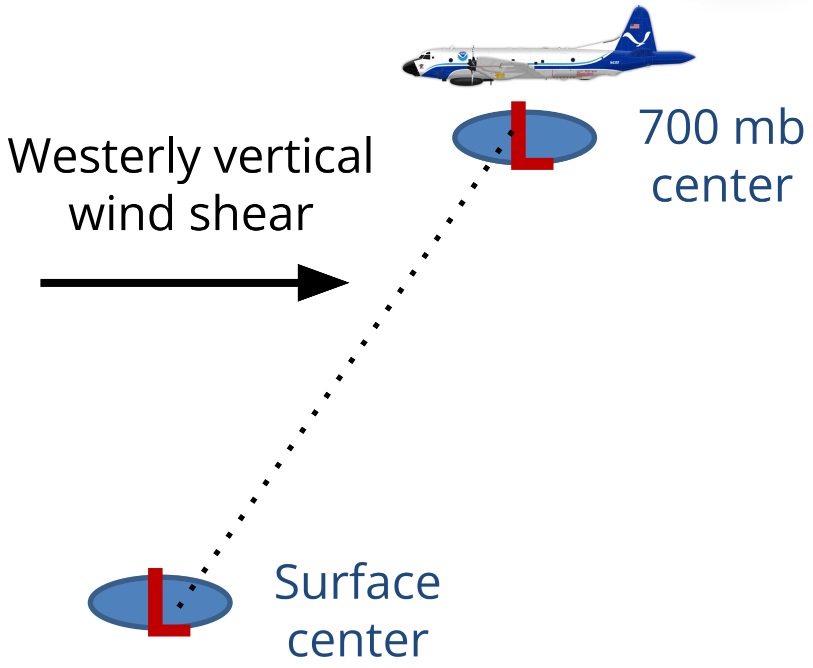
A. Date and time of fix
B. Lat/Lon of center position
C. Minimum height at standard pressure level
D. Minimum sea-level pressure
E. Surface wind from center dropwindsonde
F. Eye characteristic
G. Eye shape/orientation/diameter
H. Maximum inbound observed surface wind
I. Bearing, range, and time of (H).
J. Maximum inbound observed FL wind
K. Bearing, range, and time of (J).
L. Maximum outbound observed surface wind
M. Bearing, range, and time of (L).
N. Maximum outbound observed FL wind.
O. Bearing, range, and time of (N).
P. Max FL T/PA observed outside of eye.
Q. Max FL T/PA observed inside the eye.
R. TD/SST observed inside the eye.
S. Fix determined by…
T. Fix accuracy (navigational, meteorological)
U. AC ID, mission ID, storm name, ob number
Additional Remarks

Center Estimates

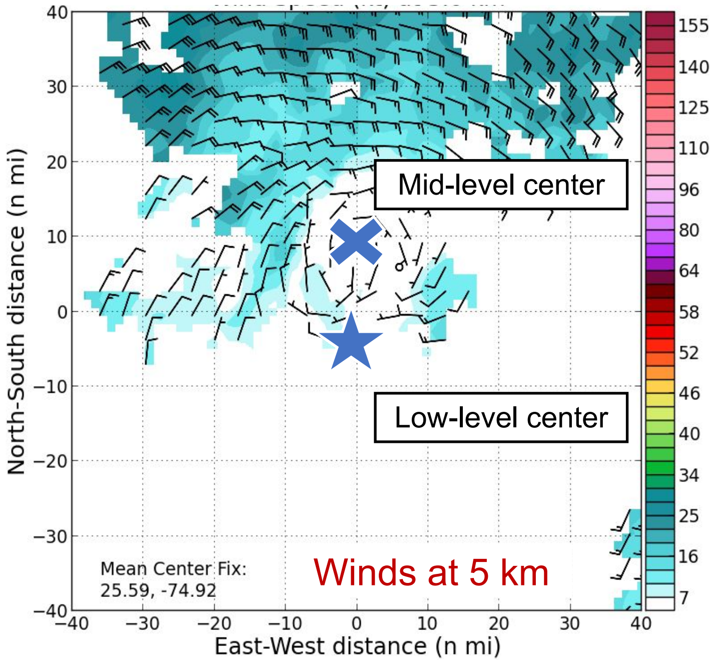
- The Hurricane Hunters provide a center fix position at flight level (e.g., 700 mb, 850 mb, 925 mb)

- Remember: We are trying to locate the center of the TC at the surface
    - If the storm is sheared, the fix and surface centers may not align

- Dropsondes and Tail Doppler Radar data can help us to refine the surface center position

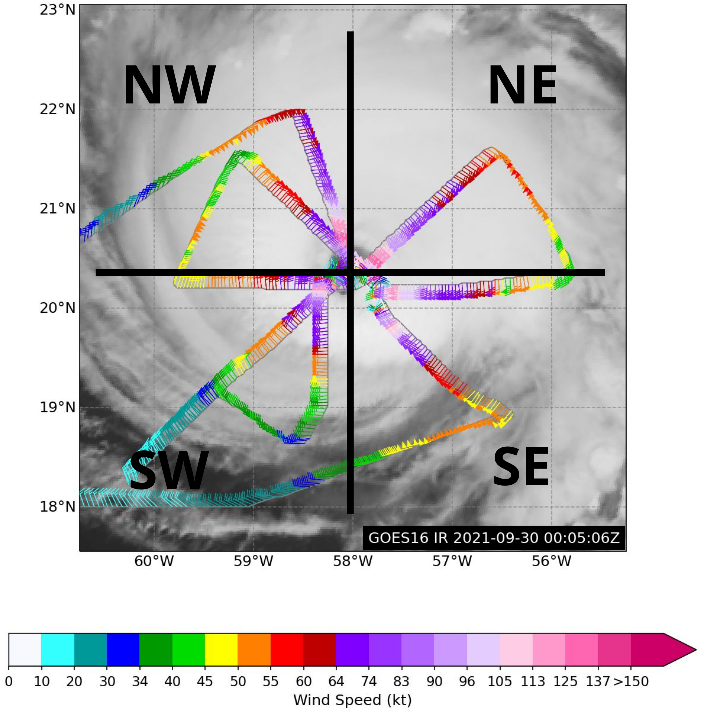


Center Estimates



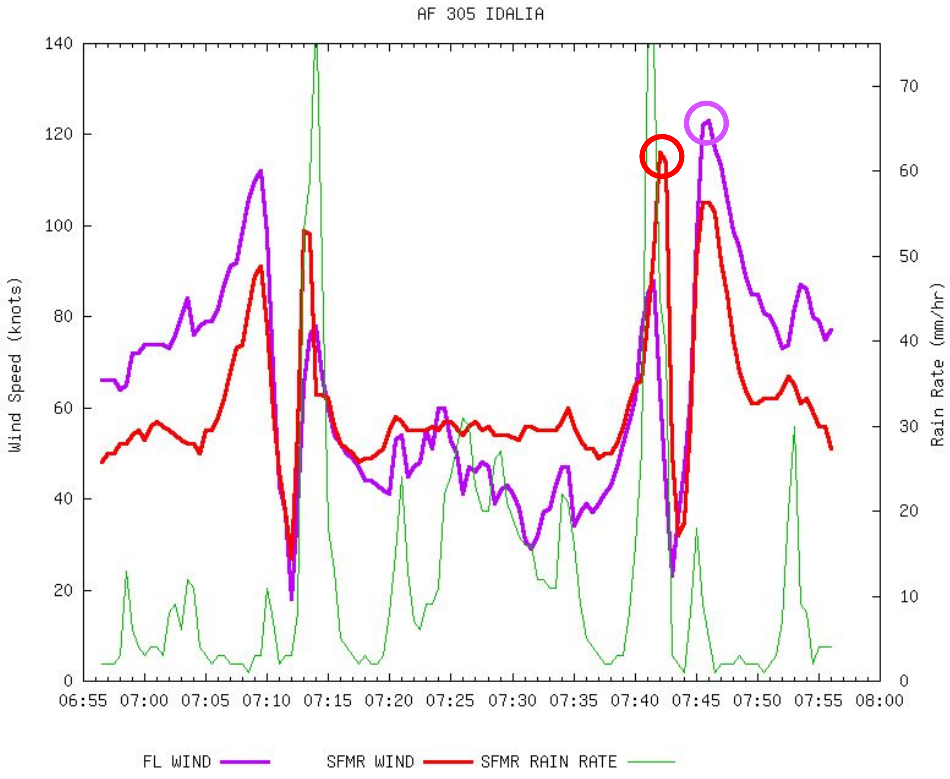
- TDR data indicates the low- and mid-level centers of this storm are not vertically aligned, likely the result of southwesterly wind shear

Size Estimates

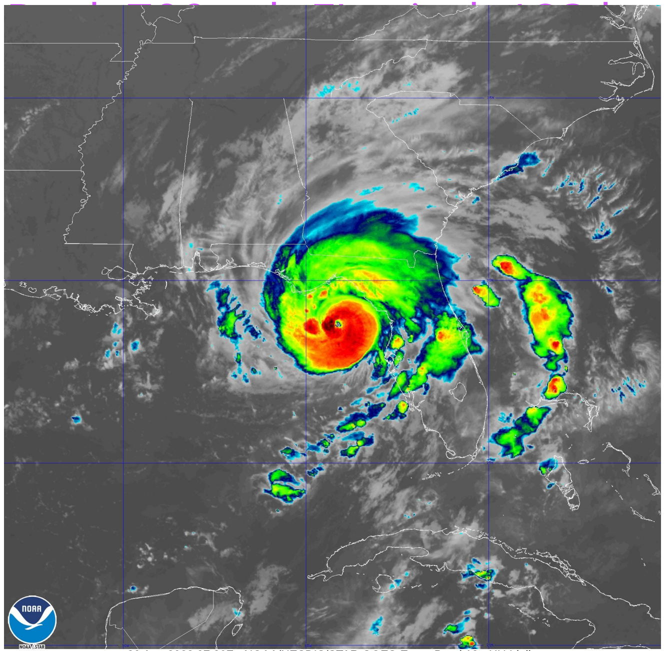


- Measure the maximum extent of 34-, 50-, and 64-kt SFMR winds in the 4 quadrants of the TC
- Radius of maximum wind (RMW): Distance from the center of a TC to the location of the cyclone's maximum winds
- The RMW along flight legs can be found in the Vortex Data Message

Intensity Estimates

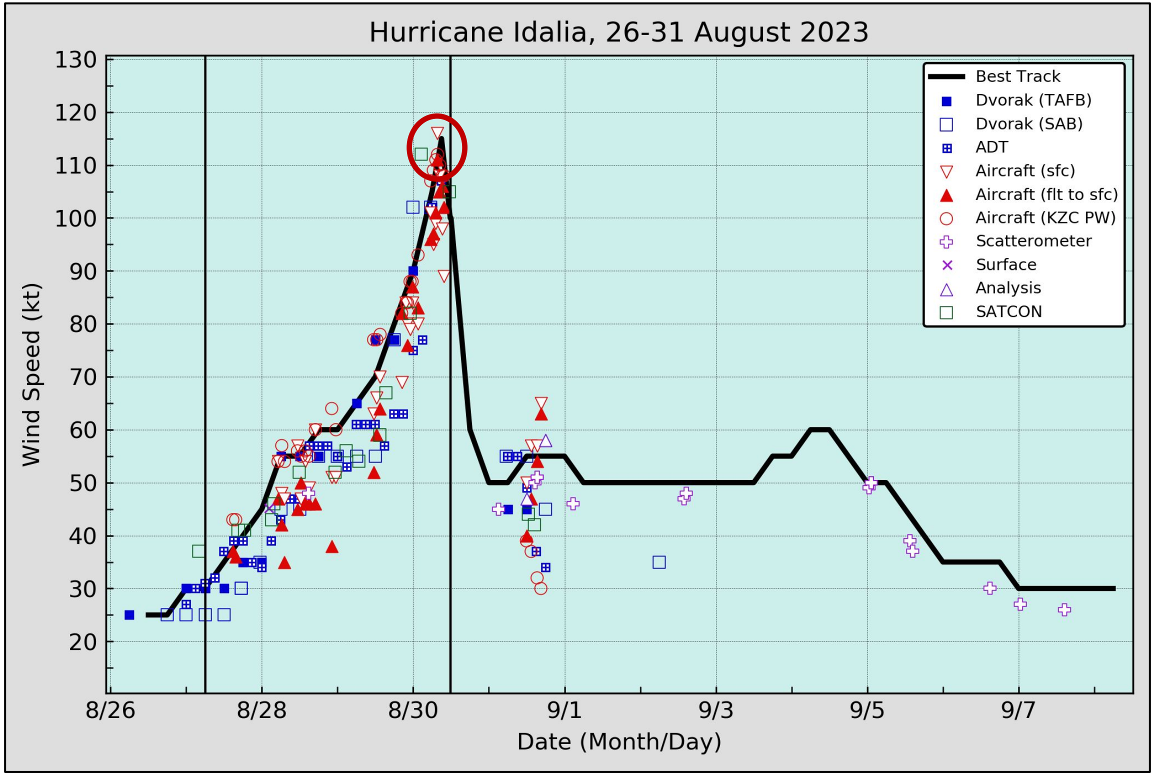


Hurricane Idalia

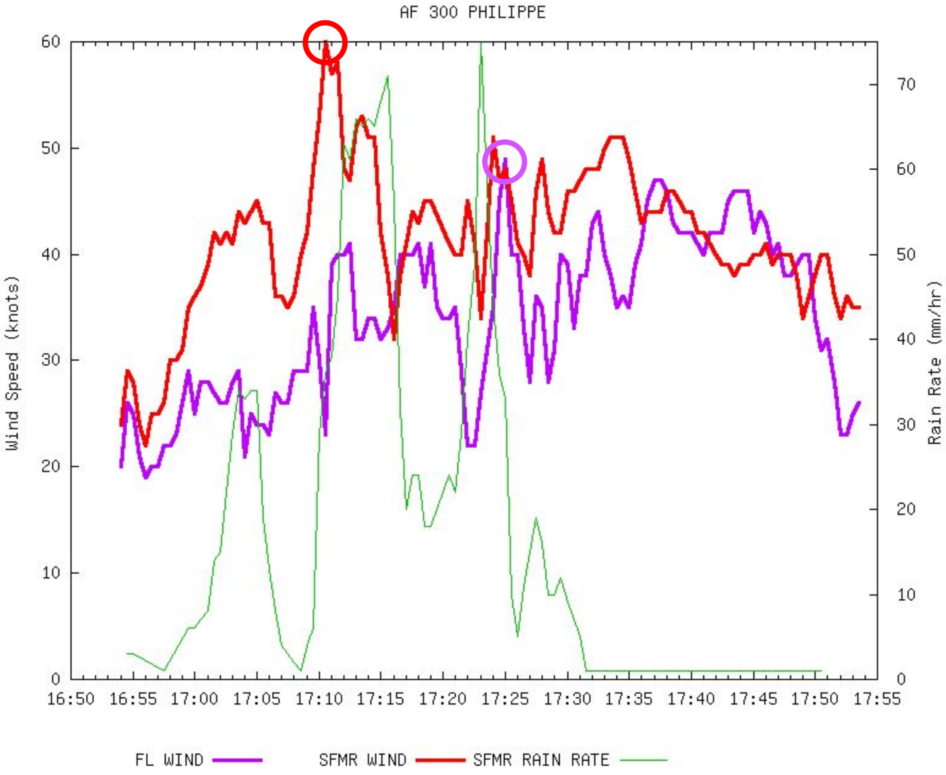


30 Aug 2023 07:30Z - NOAA/NESDIS/STAR GOES-East - Band 13 - HU Idalia

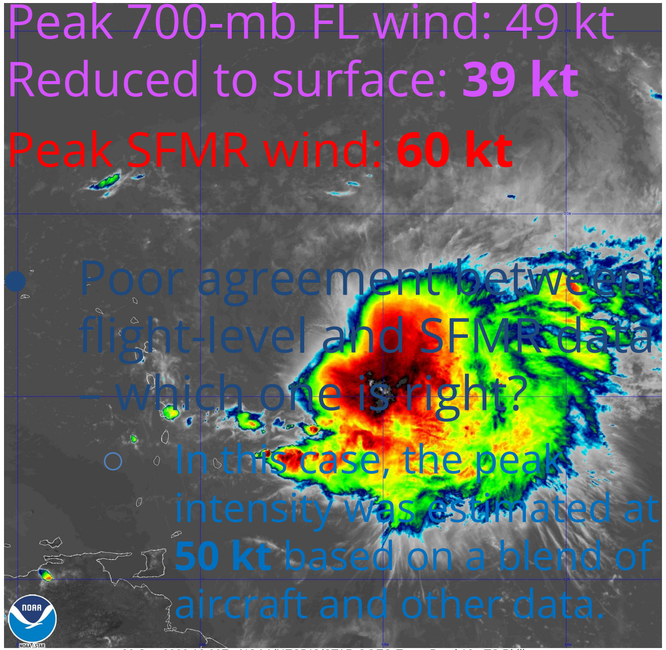
Hurricane Idalia (2023)



Intensity Estimates



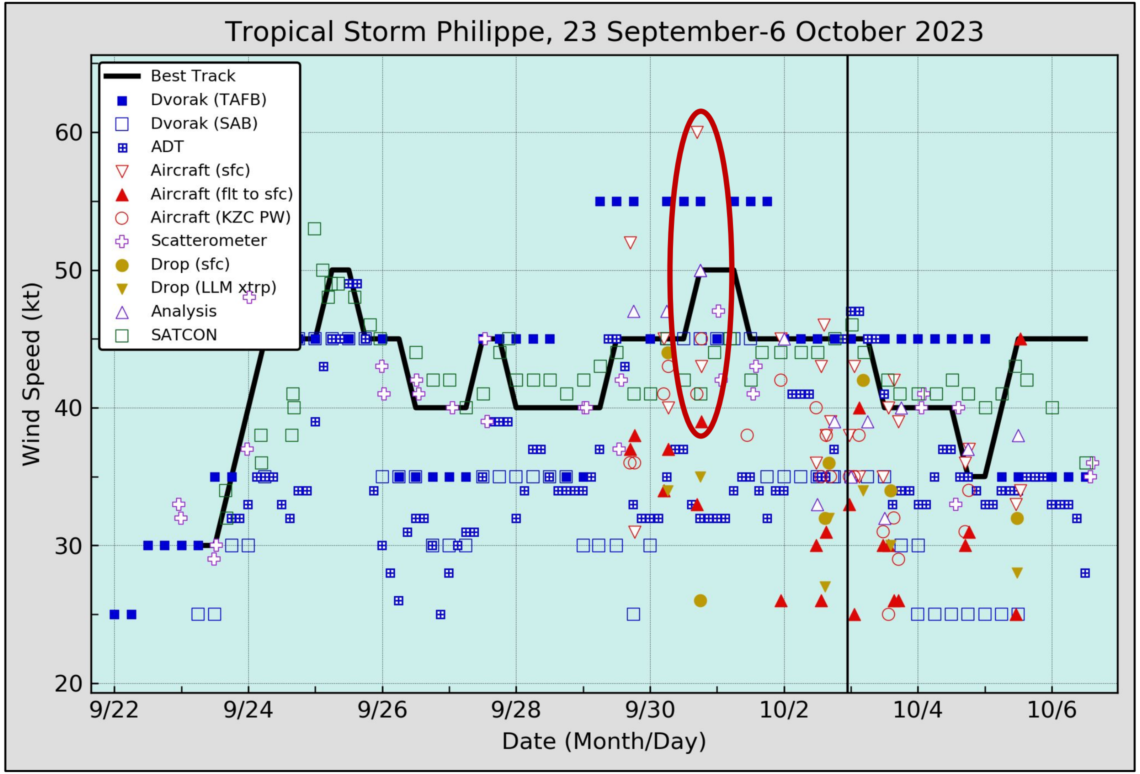
Tropical Storm Philippe



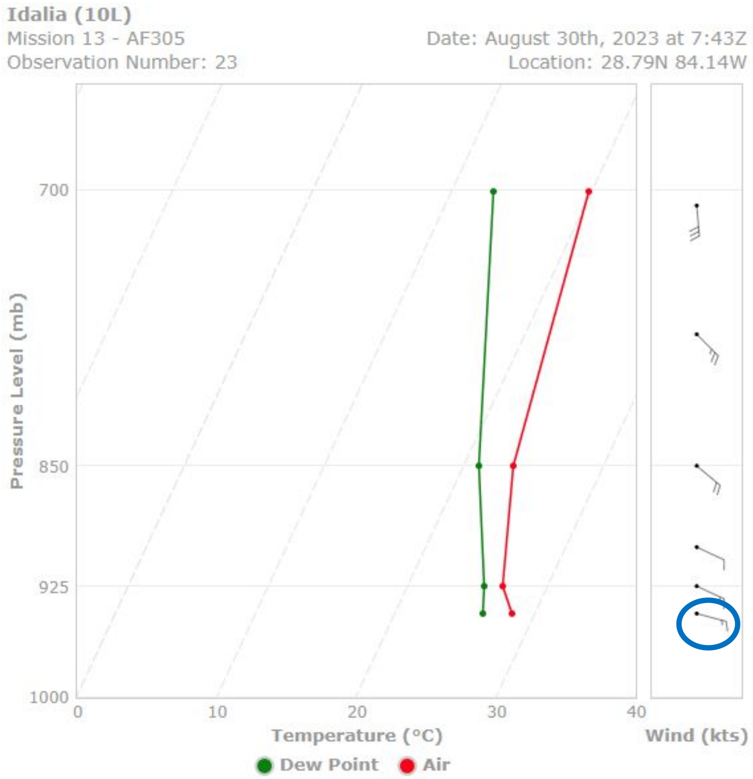
30 Sep 2023 18:00Z - NOAA/NESDIS/STAR GOES-East - Band 13 - TS Philippe

- Poor agreement between flight-level and SFMR data – which one is right?
  - In this case, the peak intensity was estimated at **50 kt** based on a blend of aircraft and other data.

Tropical Storm Philippe (2023)



Minimum Pressure Estimates



Hurricane Idalia

Dropsonde data

- Surface ("splash") pressure: 943 mb
- Surface wind: 105° (ENE) / 16 kt

Rule of thumb: Subtract 1 mb from the dropsonde splash pressure for each full 10 kt of surface wind reported by the dropsonde.

Estimated minimum pressure: **942 mb**

NHC Post-Analysis

- NHC routinely performs a post-storm analysis of every tropical storm and hurricane
- These analyses can result in changes to intensity estimates, storm status, etc. from the real-time assessment
- Changes are reflected in the final best track once the Tropical Cyclone Report is completed

NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE IDALIA
(AL102023)

26–31 August 2023

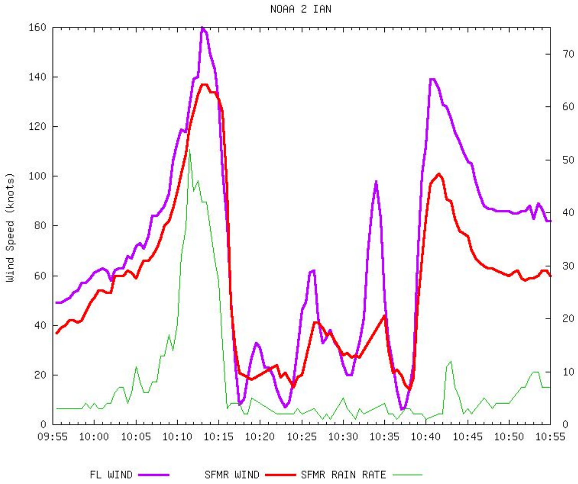
John P. Cangialosi and Laura Alaka
National Hurricane Center
13 February 2024

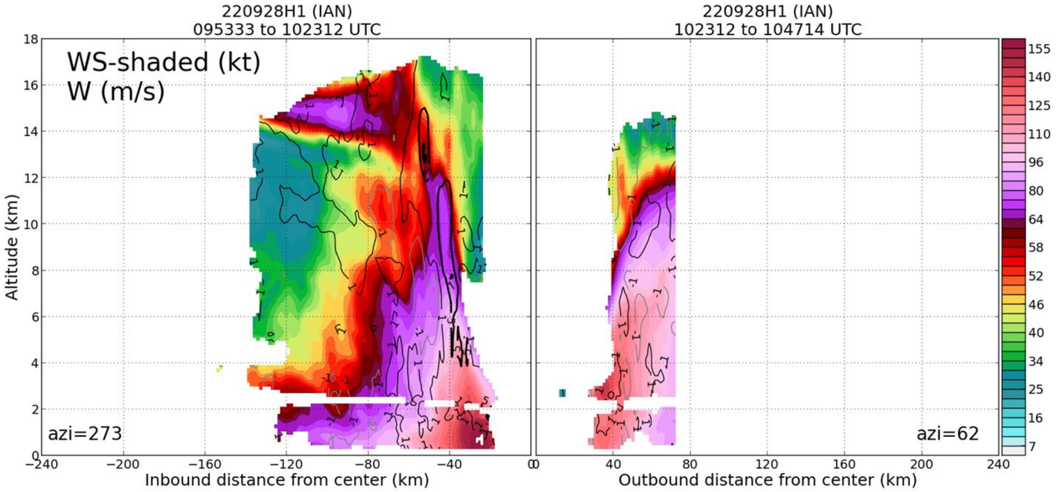
GOES-16 GEOCOLOR IMAGE OF HURRICANE IDALIA AT 0715 UTC 30 AUGUST 2023.
IMAGE COURTESY OF NOAA/NESDIS/STAR.

Idalia was a category 4 hurricane (on the Saffir Simpson Hurricane Wind Scale) that rapidly intensified over the Gulf of Mexico. It made landfall as a category 3 hurricane along the Florida Big Bend and is the third strongest landfalling hurricane in modern history for that region. Idalia is responsible for 12 fatalities and an estimated $3.6 billion in damage in the United States.

Hurricane Ian (2022)

- Last season, post-analysis of the aircraft data collected in Hurricane Ian justified raising its peak intensity to 140 kt (Cat. 5) offshore of Florida.
  - Flight-level winds, SFMR, and TDR data all contributed to this analysis





Closing Thoughts

- Like any dataset, aircraft observations have limitations that may complicate the interpretation of the data.

- Hurricane specialists attempt to synthesize and blend the data in an intelligent manner that recognizes the strengths & weaknesses of each data source.

- NHC's analyses of TC intensity and size have considerable error.
    - Intensity only good to within ~10% (e.g., 100 kt +/- 10 kt)
    - TS wind radii to about ~25% (e.g., 120 nm +/- 30 nm)
    - HU wind radii to about ~40% (e.g., 25 nm +/- 10 nm)

The Use of TC Reconnaissance Data in NOAA NWP

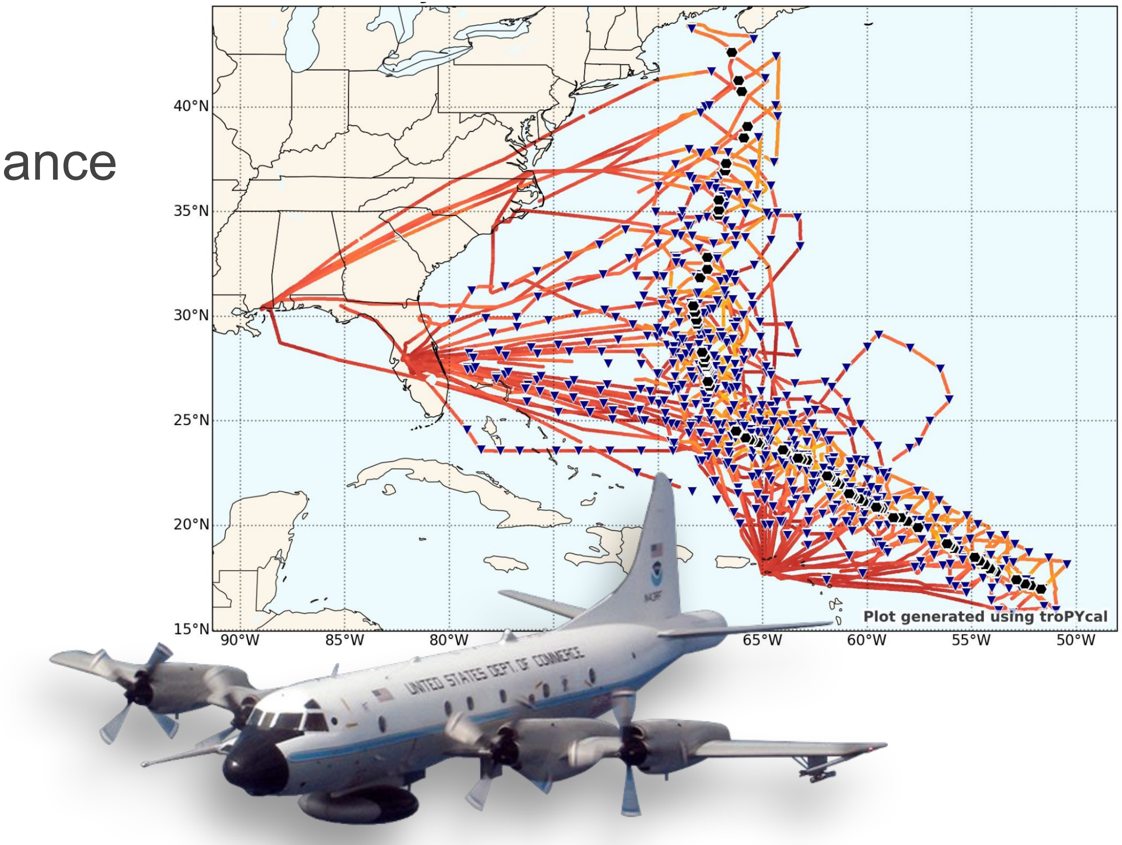
Jason Sippel
NOAA AOML/HRD

OAR
&
NWS

National Hurricane Conference
March 27, 2024

Outline

- History of assimilating (ingesting) reconnaissance data in NOAA models
- Where we stand
- Where we're going



Outline

- History of assimilating (ingesting) reconnaissance data in NOAA models
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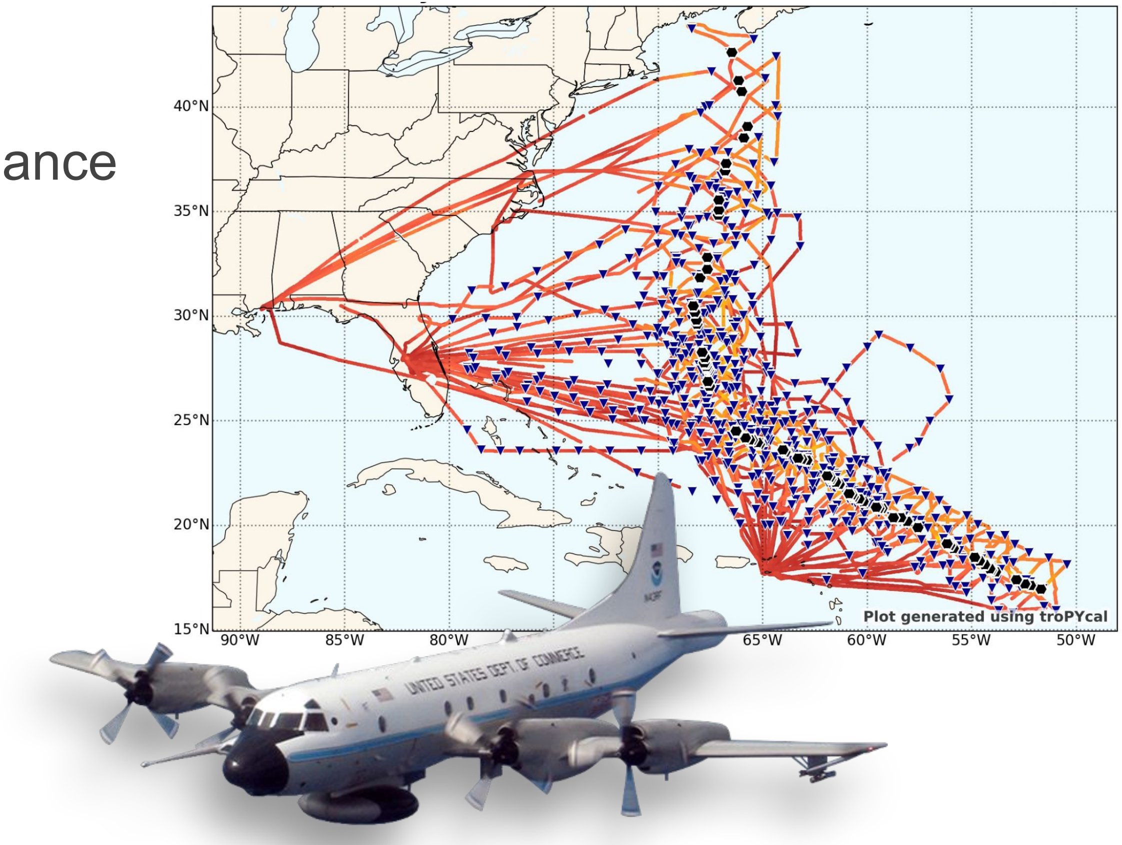
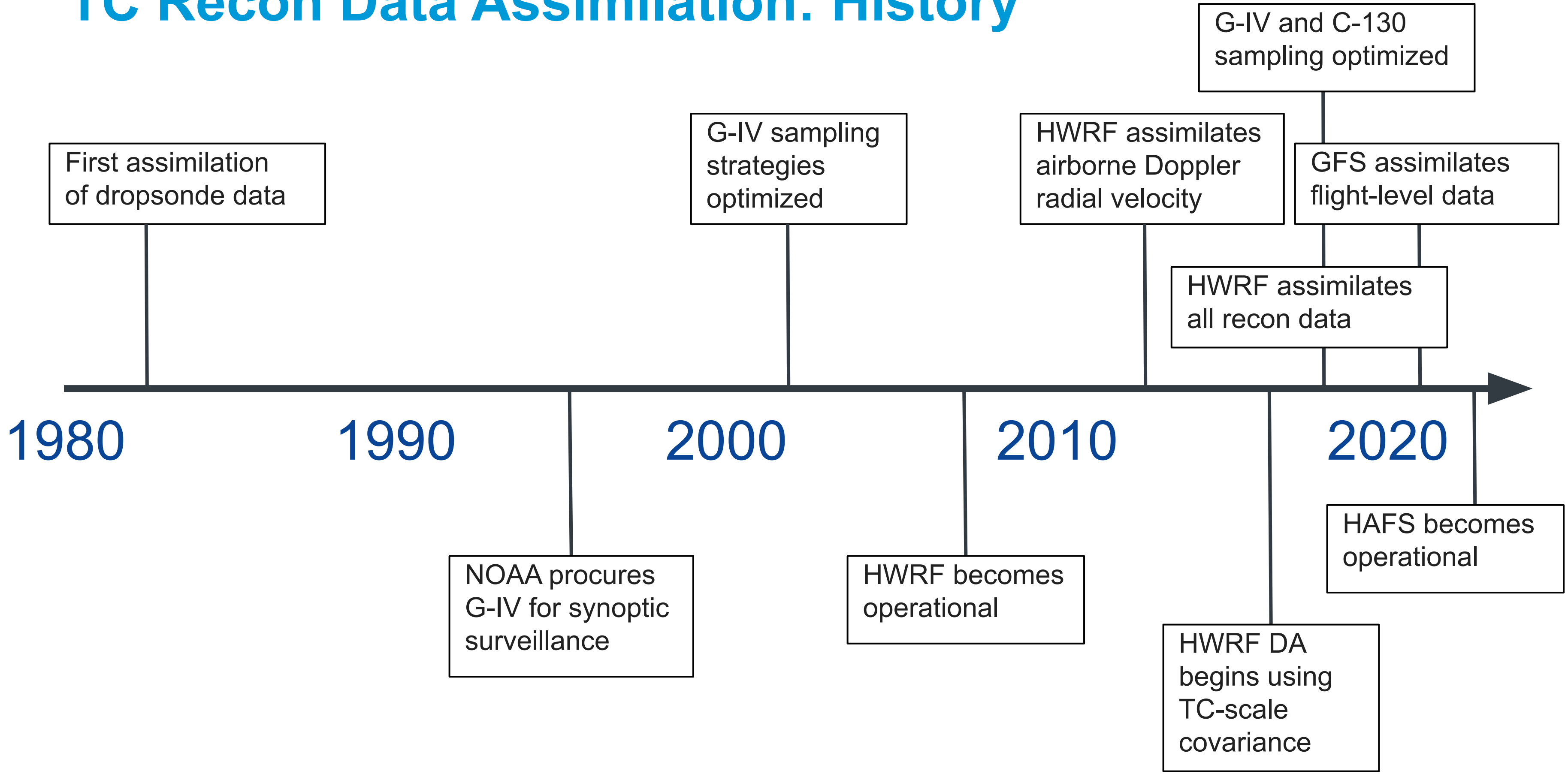
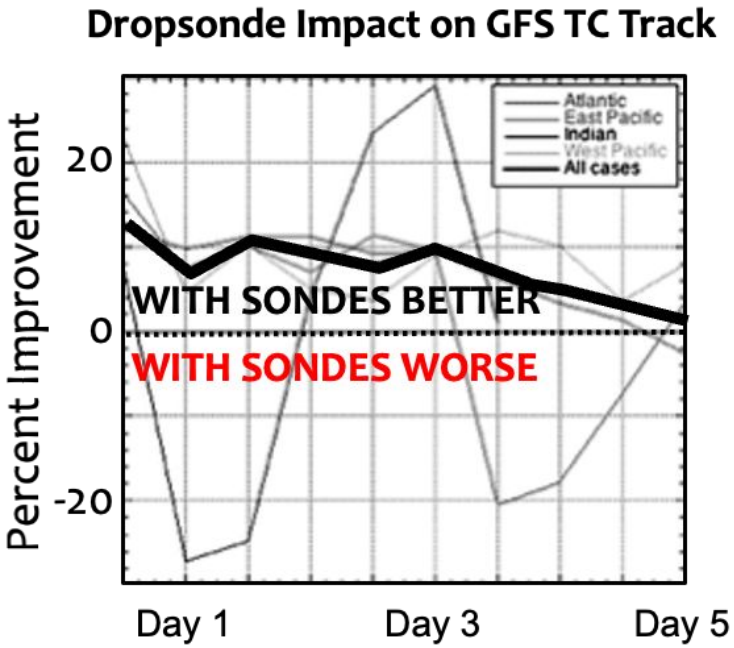
- Where we're going



TC Recon Data Assimilation: History



TC Recon Data Assimilation: Dropsondes



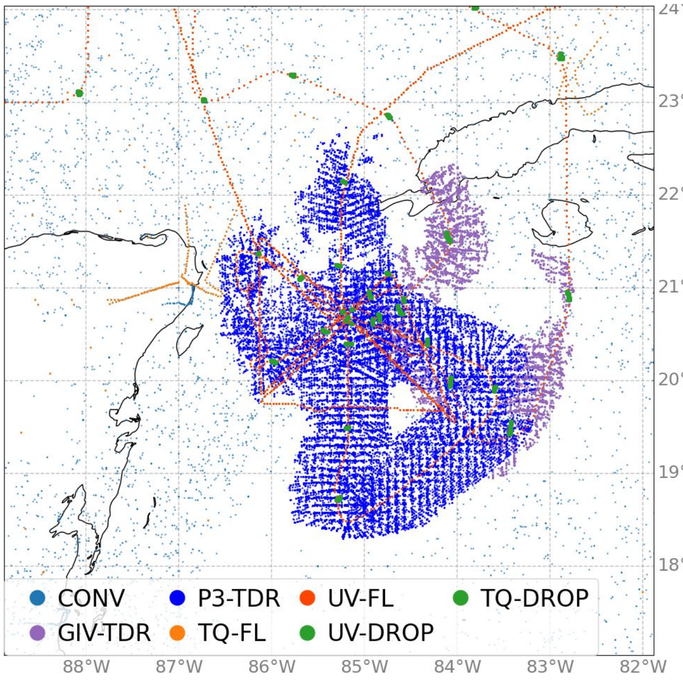
Impact of dropsondes in September 2008

- US has used dropsondes in weather models for ~40 years
- “Environmental” data easier to deal with than “in-vortex” data
- Many studies have shown dropsondes improve TC track forecasts

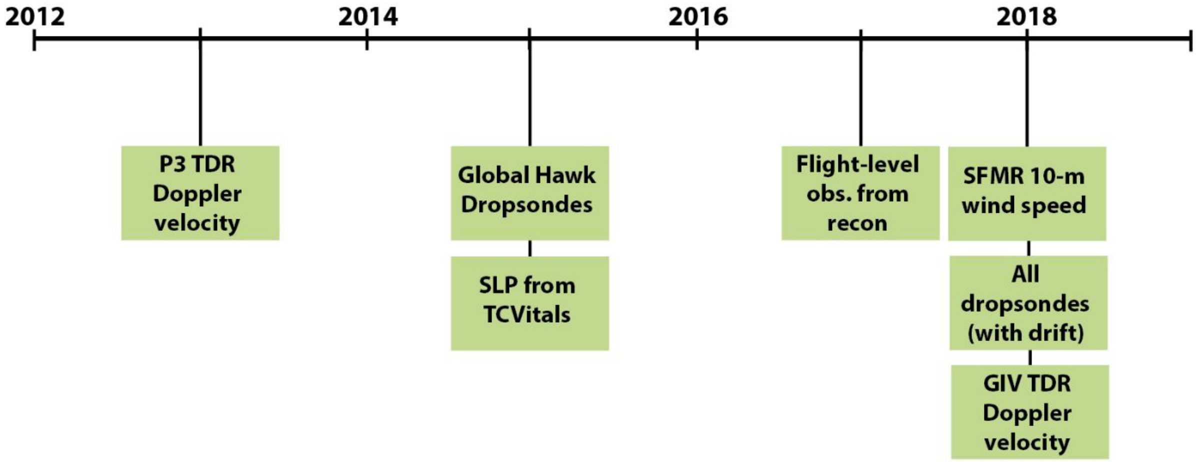
TC Recon Data Assimilation: In-vortex Data

- DA research with Doppler velocity (88D) in TCs began ~15 years ago
- Operational assimilation of airborne Doppler velocity (TDR) begin ~10 years ago
- Use has expanded greatly over past decade

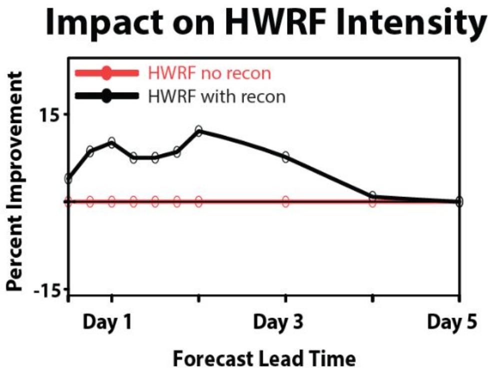
Data Assimilated in Idalia



TC Recon Data Assimilation: In-vortex Data

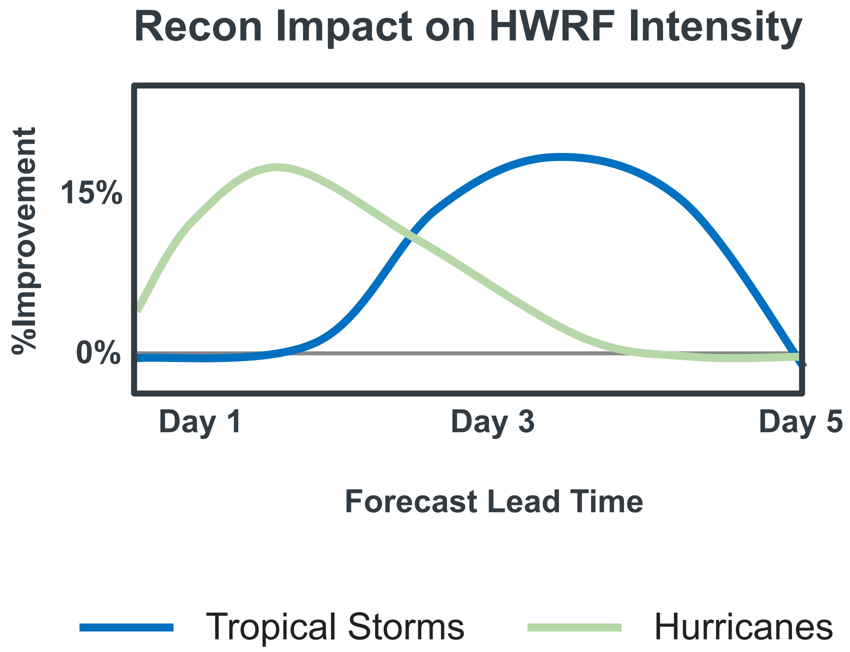


RECONNAISSANCE DATA IN HWRF

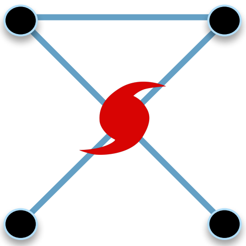


TC Recon Data Assimilation: In-vortex Data

- For tropical storms, recon data improves long-term intensity forecasts
- For hurricanes, recon data improves short-term intensity forecasts
- This matches theoretical expectations

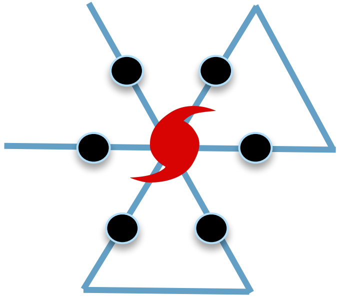


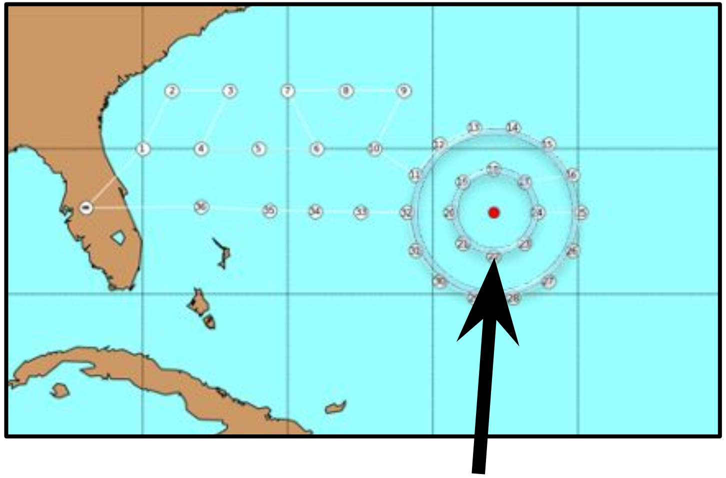
TC Recon Data Assimilation: Optimizing Strategies



USAF C-130:
Added end-point dropsondes

NOAA P3:
Added mid-point dropsondes





G-IV: Added Inner Circumnavigation

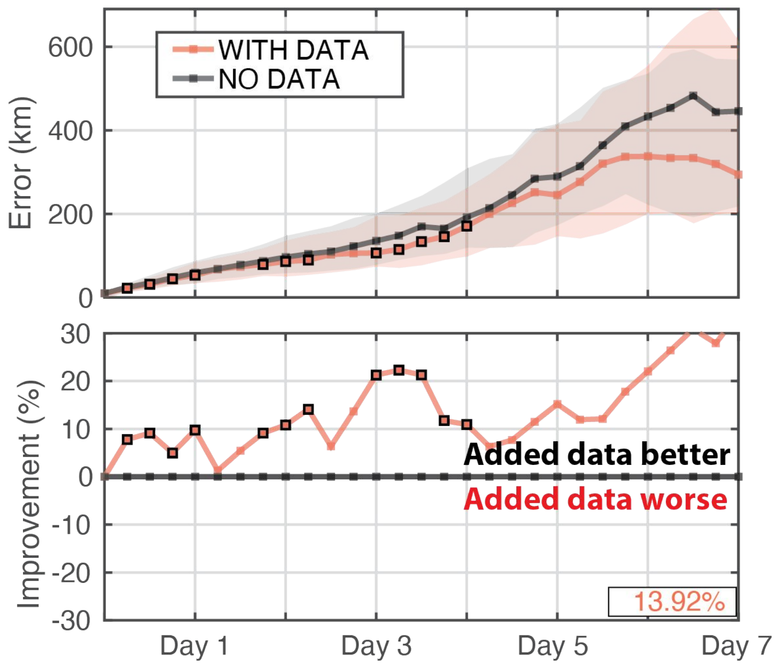
Sampling changes in 2017-18 have improved forecasts

TC Recon Data Assimilation: GFS Improvements

- GFSV16 upgrade in March 2021 included better use of dropsondes and flight-level data

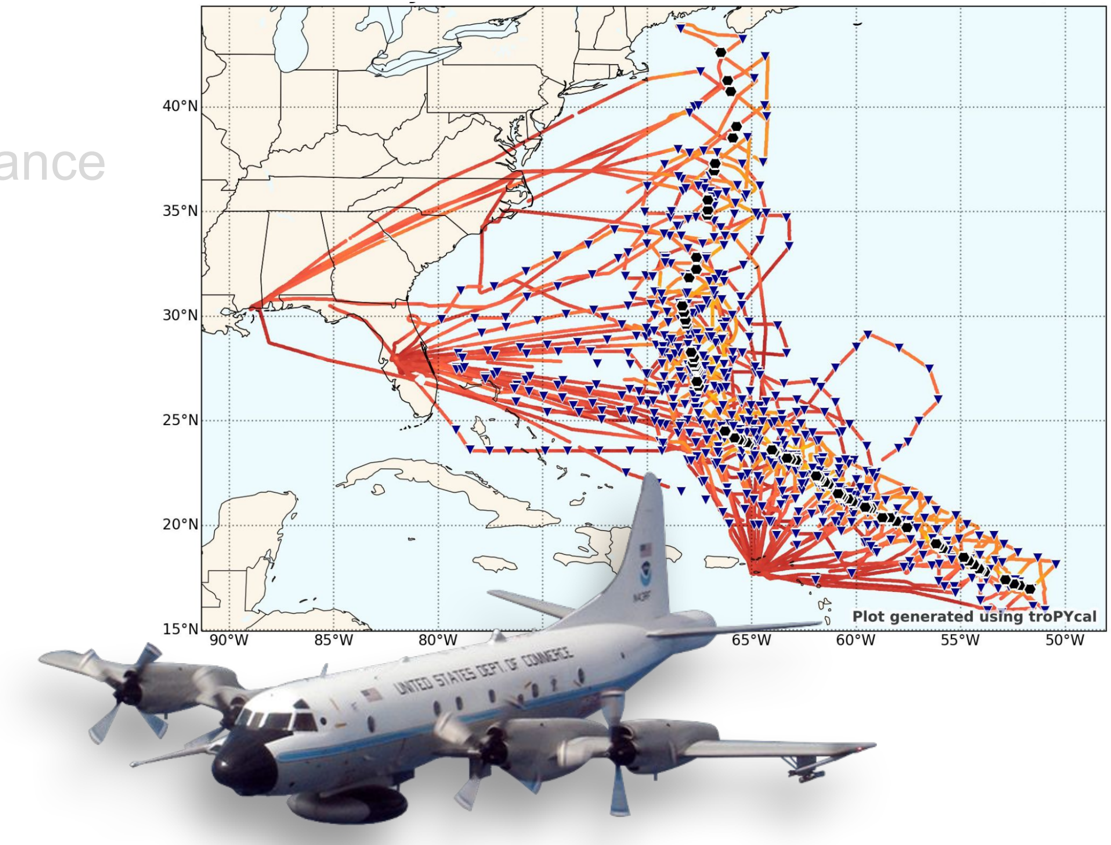
- Added data improves track in sampled storms 10-20%

Additional recon impact on GFS track

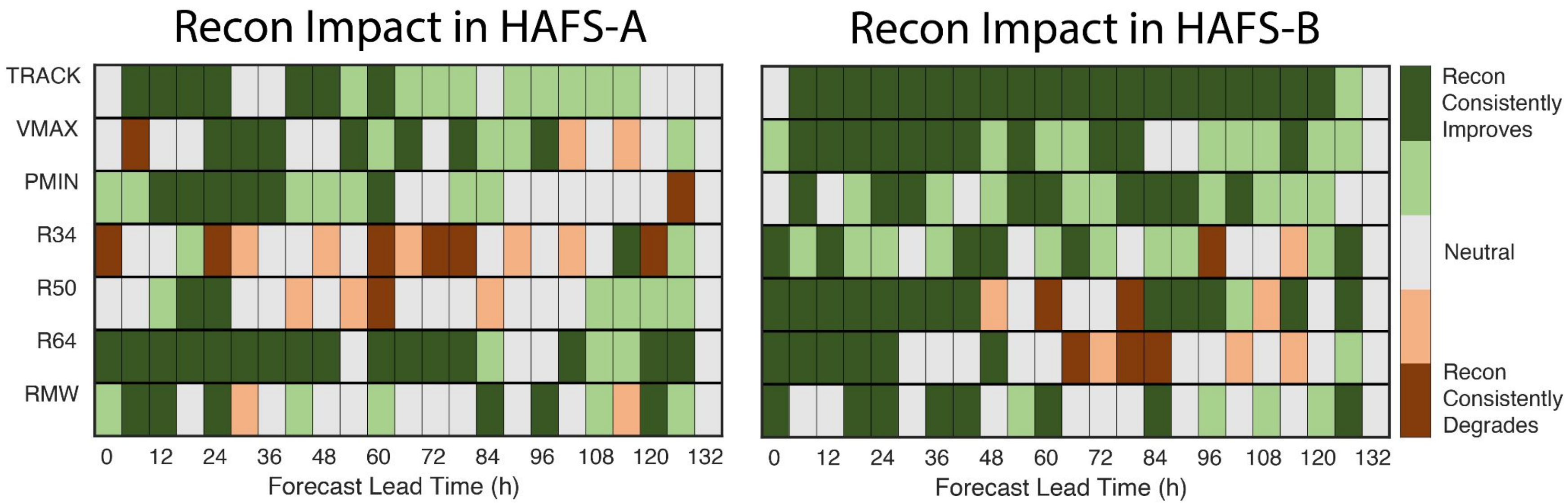


Outline

- History of assimilating (ingesting) reconnaissance data in NOAA models
- Where we stand
- Where we're going

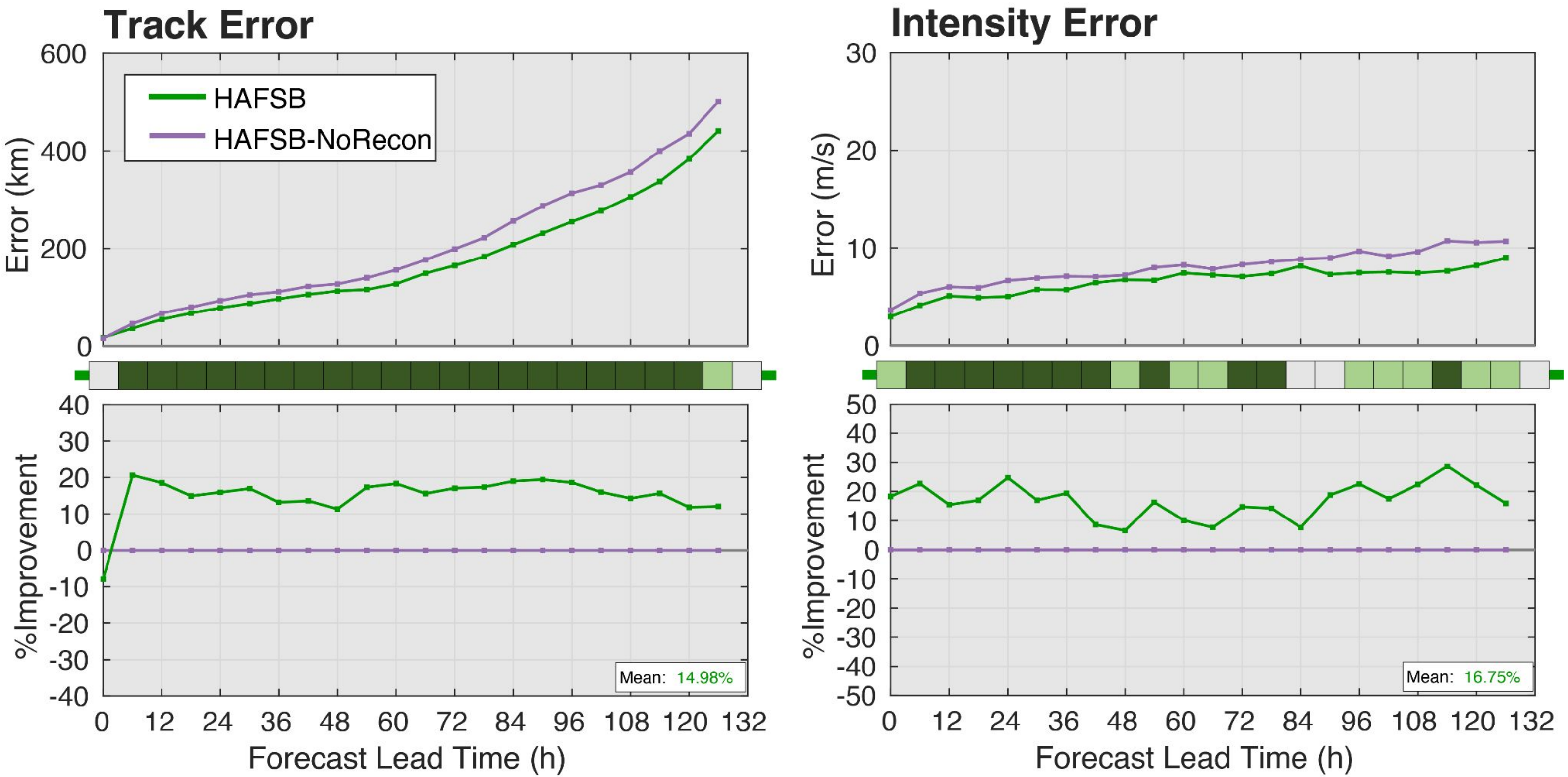


Where We Stand: Recon Impact in HAFS

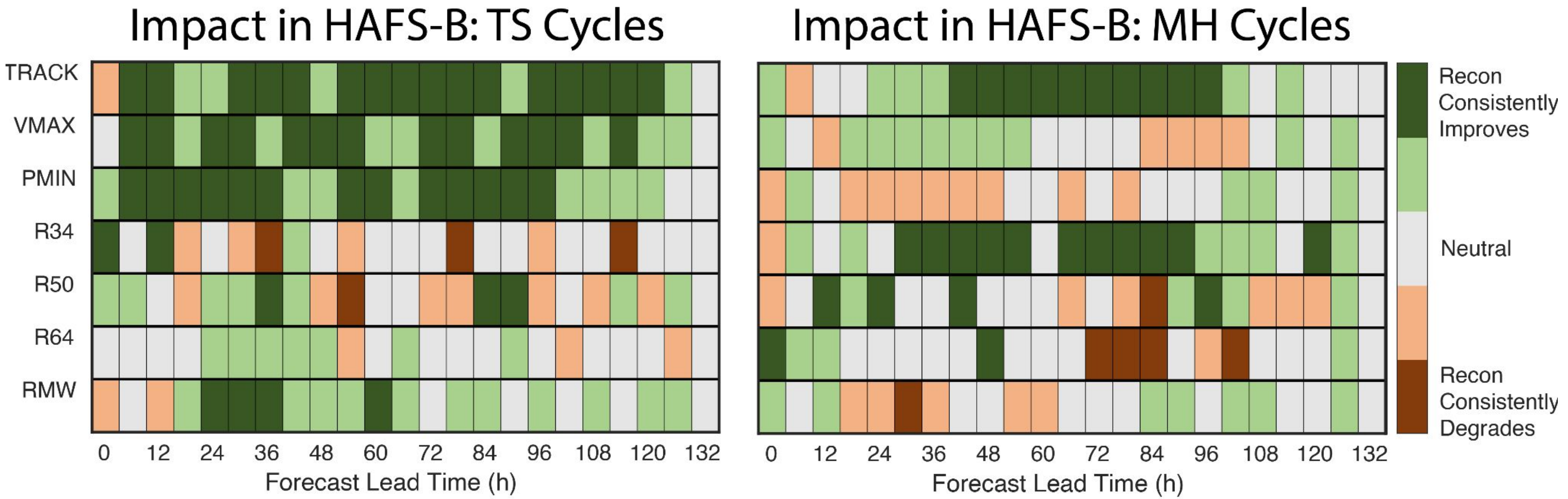


- Recon data impacts positive in both versions of HAFS
- Not as good in HAFS-A due to a setting in TS (improving in 2024)

Where We Stand: Recon Impact in HAFS



Where We Stand: Impact in Weak vs. Strong Storms

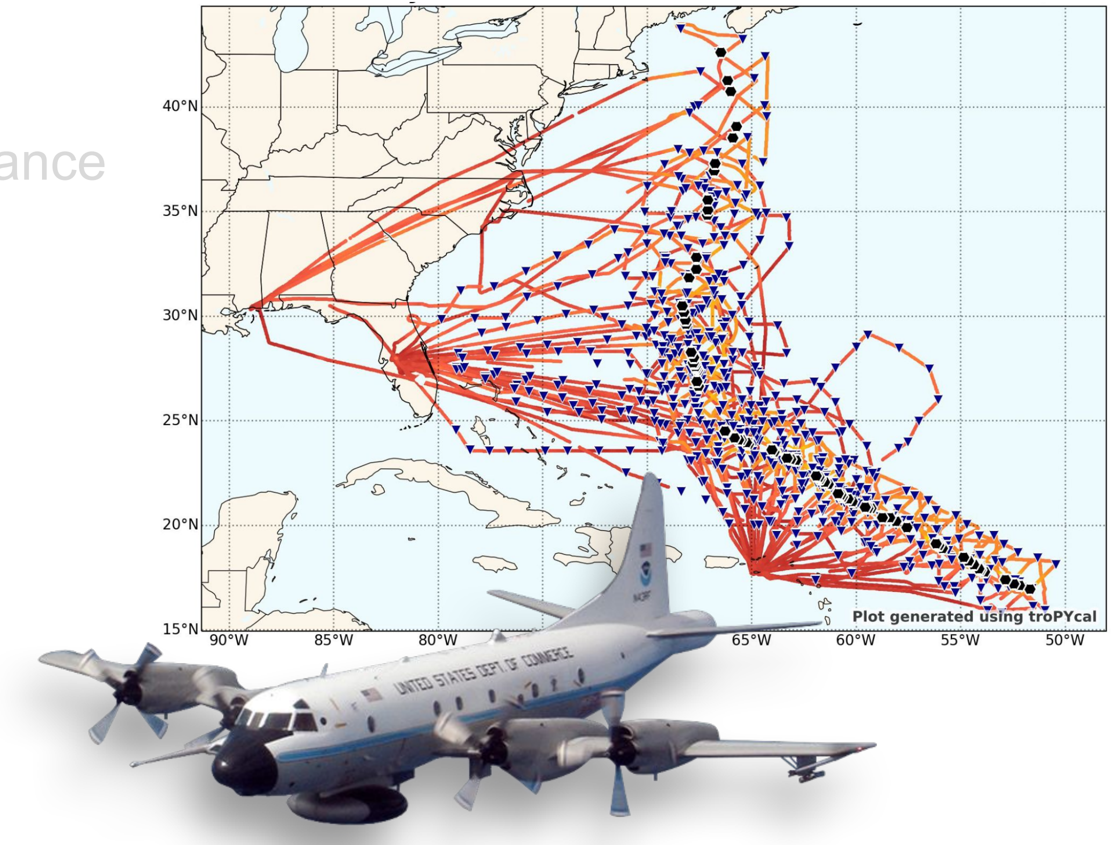


Recon Impacts Compared with HWRF

- Better impact on track than in HWRF
- Impact on intensity varies: better for weak storms, worse for strong storms

Outline

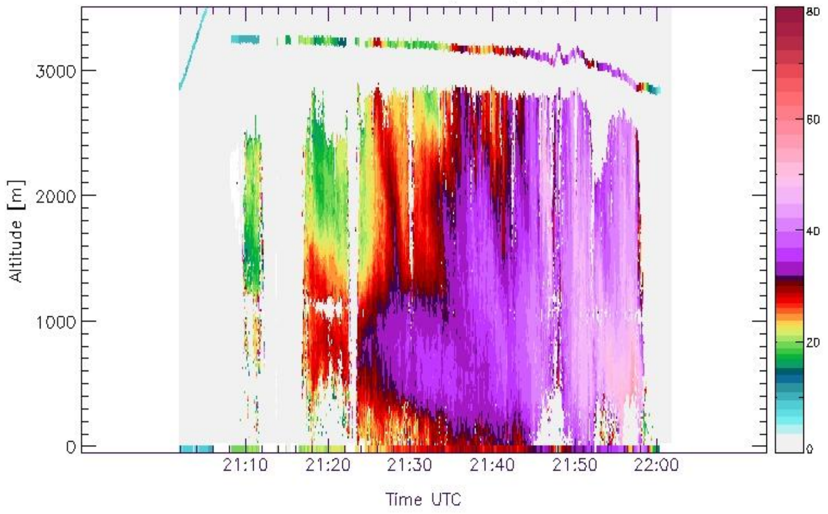
- History of assimilating (ingesting) reconnaissance data in NOAA models
- Where we stand
- Where we're going



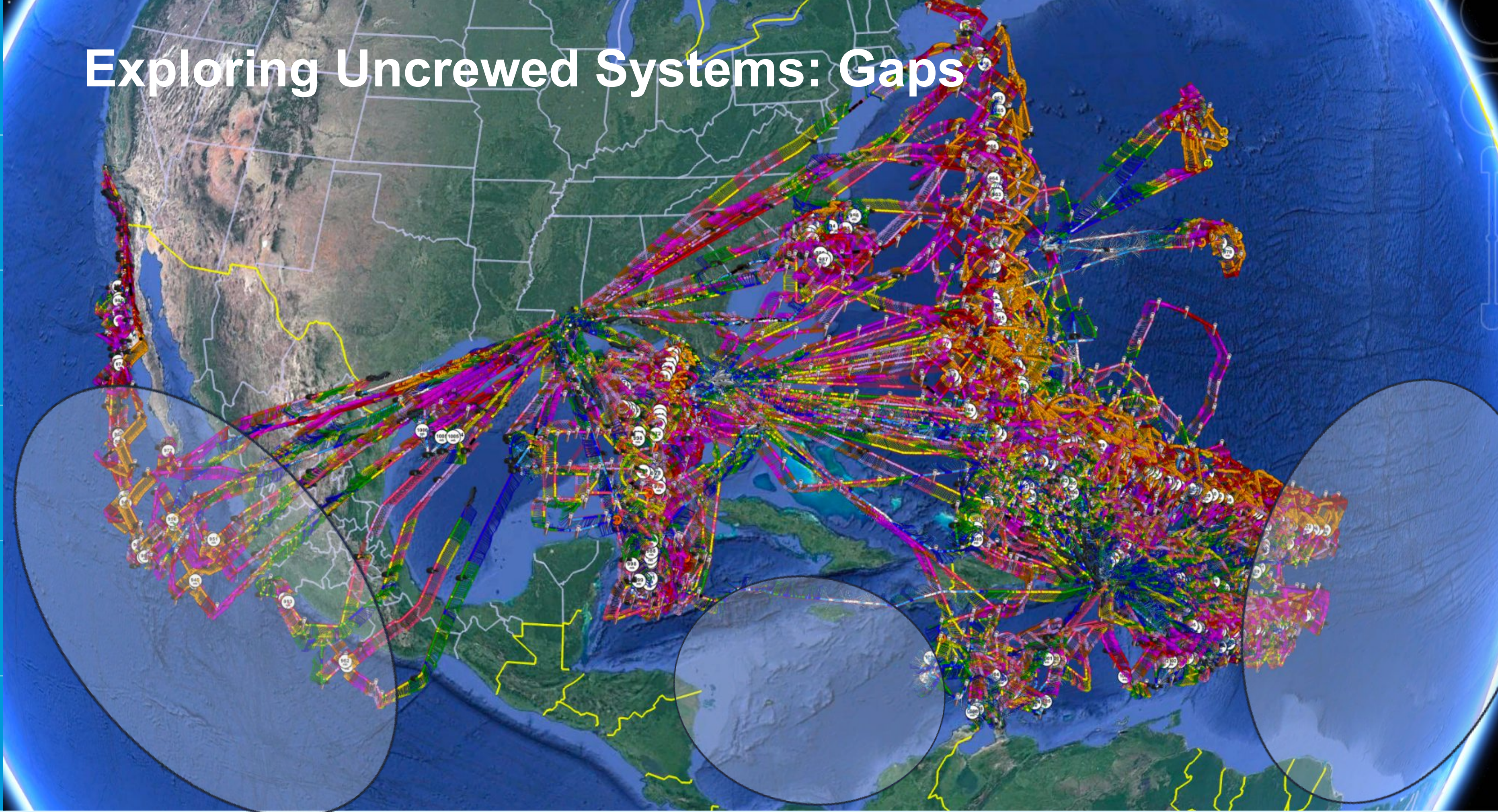
Where We're Going: Priorities

- Improve DA methodology
- Bring other airborne data sources online
- **Explore uncrewed systems**

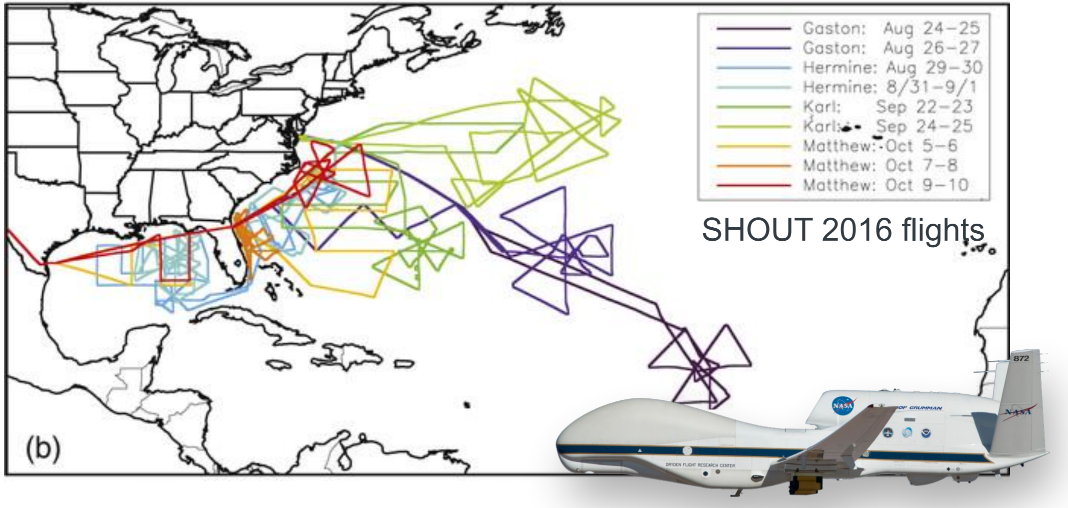
Horizontal Winds in Ian from IWRAP

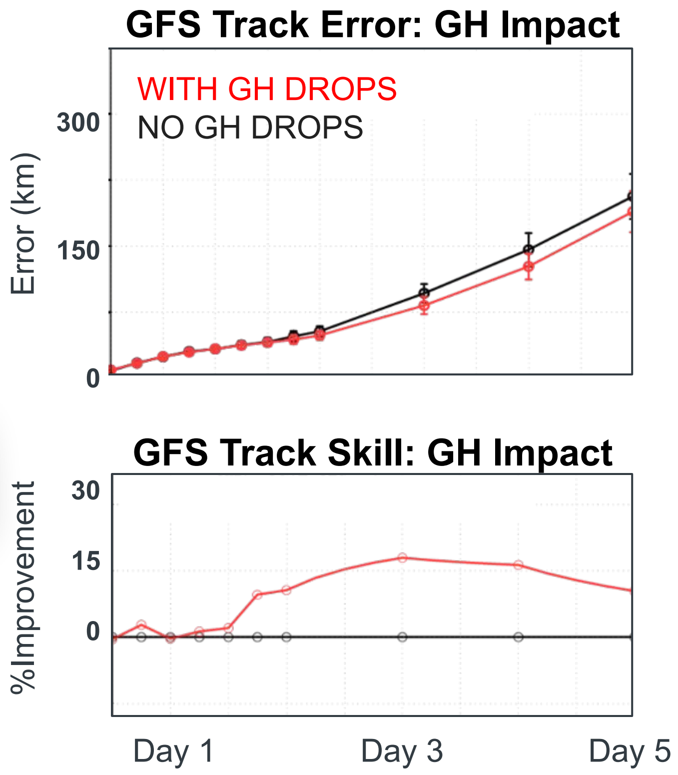


Exploring Uncrewed Systems: Gaps



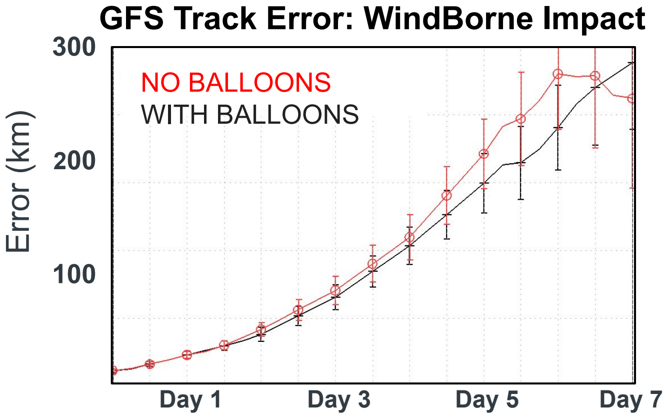
Exploring Uncrewed Systems: Global Hawk





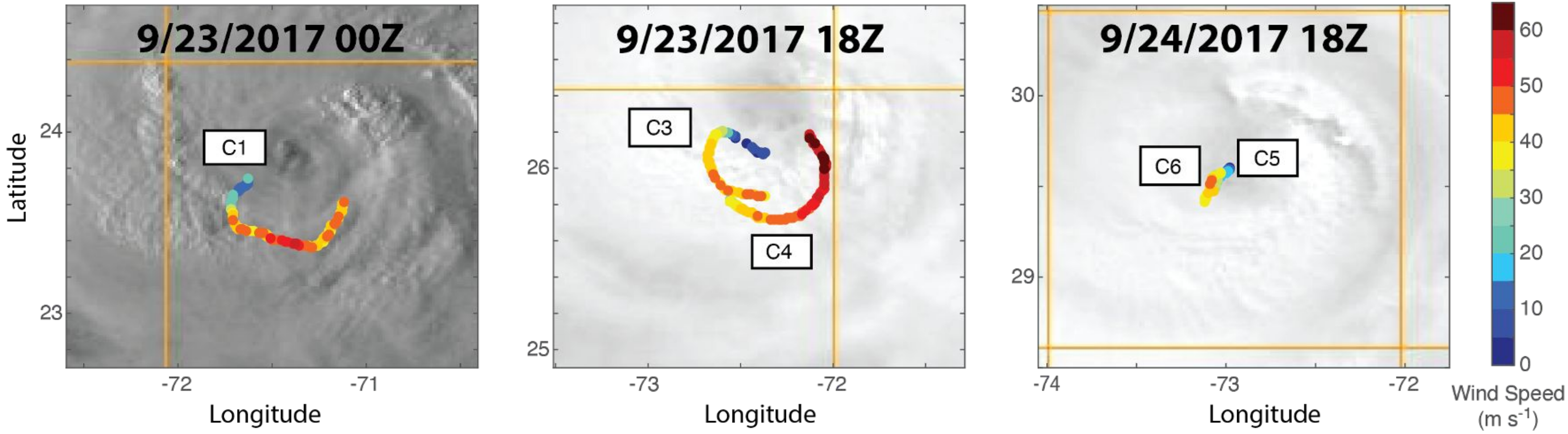
- High-altitude drops (~60 kft)
- Storm-focused UAS flights with dropsondes

Exploring Uncrewed Systems: WindBorne Balloons



- Surface to stratosphere
- Wind obs fill a MAJOR gap (mid-levels)
- Improvements to large scale and TC track

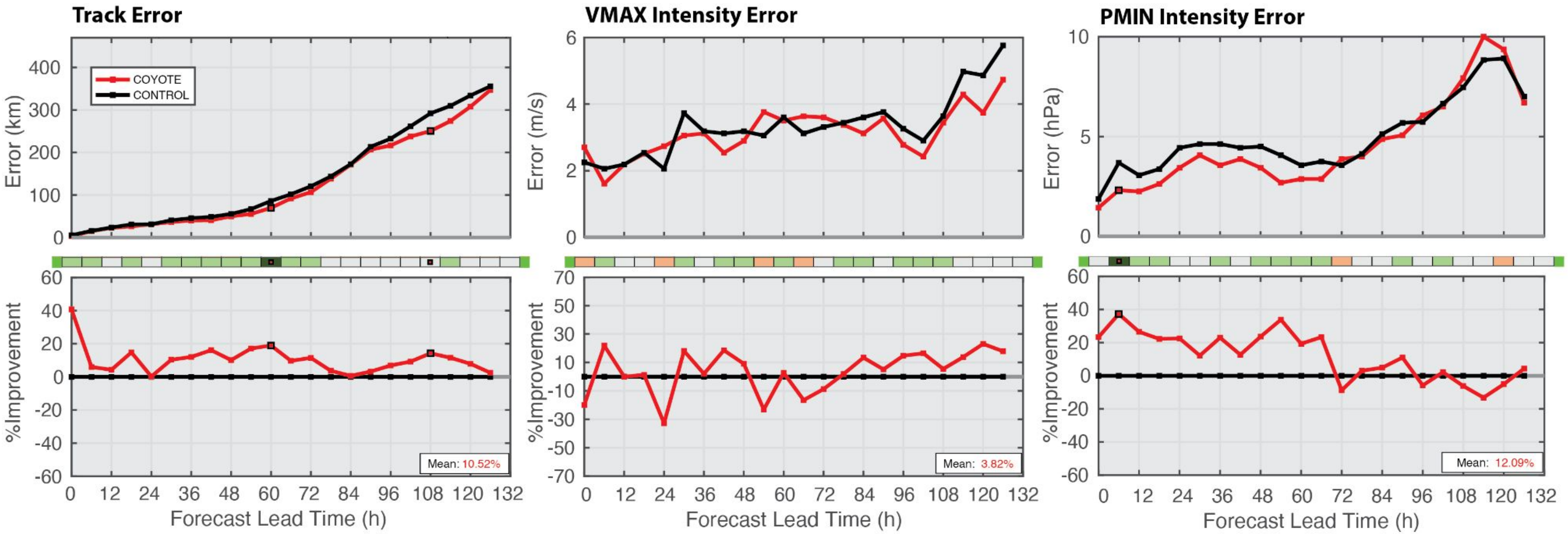
Exploring Uncrewed Systems: Small UAS



Hurricane Maria: Visible Satellite and Coyote Data

- Assimilating Coyote data in Maria improved HWRF forecasts
- Similar improvement in HAFS with Ian

Exploring Uncrewed Systems: Small UAS



- Assimilating Coyote data in Maria improved HWRF forecasts
- Similar improvement in HAFS with Ian

Summary

- NOAA has a long history of assimilating recon data from TC missions
- Earliest efforts with dropsondes extend back 40 years, while in-vortex usage has increased over past decade
- Assimilating recon data improves all aspects of TC forecasts
- How recon is used has evolved concurrently with DA systems
- The future almost certainly will include extensive use of uncrewed systems to augment crewed missions

NOAA's Atlantic Oceanographic and Meteorological Laboratory
U.S. Department of Commerce

Future of Airborne Tropical Cyclone Monitoring

Robert Rogers
Lead, Observations Team
NOAA/AOML Hurricane Research Division
Miami, FL

Airborne Hurricane Monitoring

- The first aircraft mission into a hurricane occurred in 1943. Aircraft missions became routine in the 1950s.
- These missions have always provided valuable information on hurricane location, intensity, and structure for forecasters.
- Research missions began in 1955, with the formation of the National Hurricane Research Project (NHRP) -- a precursor to HRD.
- Airborne research initially focused on understanding fundamental physical processes.
- By 2005, the emphasis for airborne data collection shifted from physical understanding to forecast improvement, particularly for hurricane intensity, including rapid intensification.

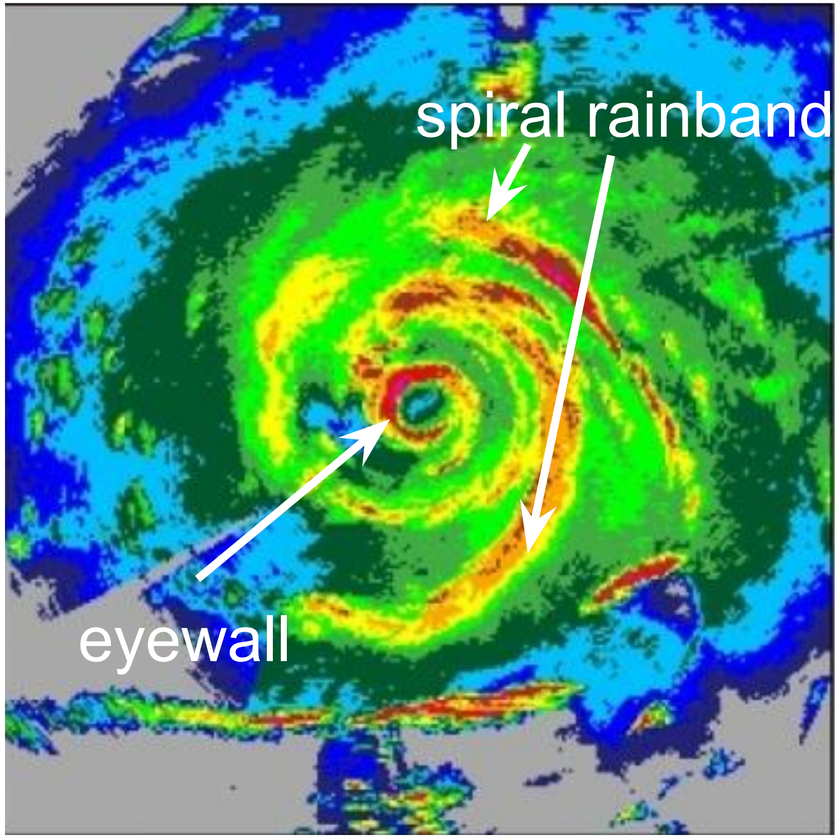
Current airborne observations - Platforms

NOAA fleet

Air Force fleet

Current airborne observations - Instruments

Lower Fuselage (LF) Radar

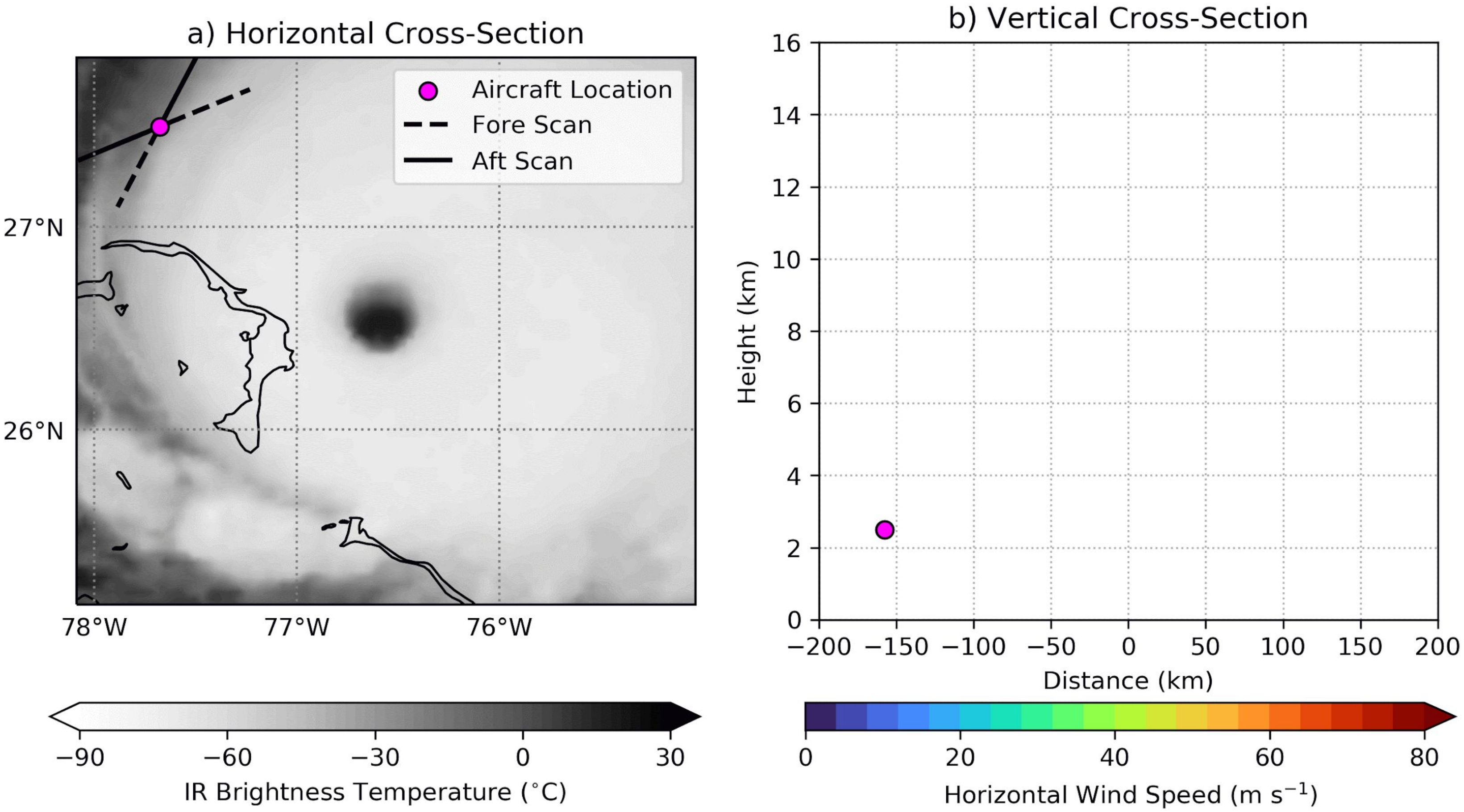


- Measurements of reflectivity in environment around aircraft
- Depictions of inner-core structure
- Crucial for crew situational awareness

Current airborne observations - Instruments

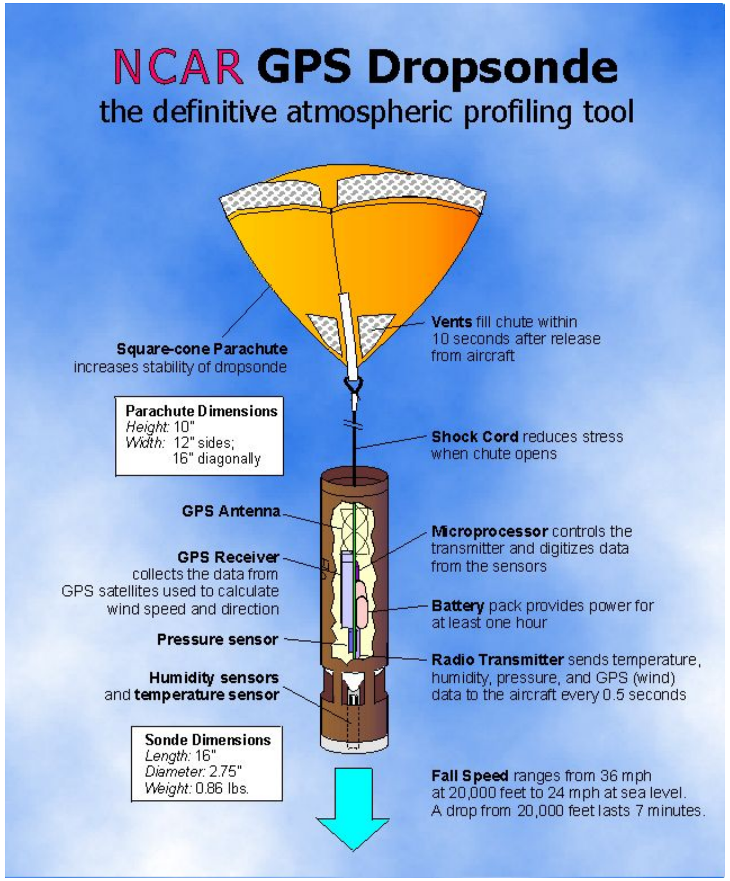
Tail Doppler Radar

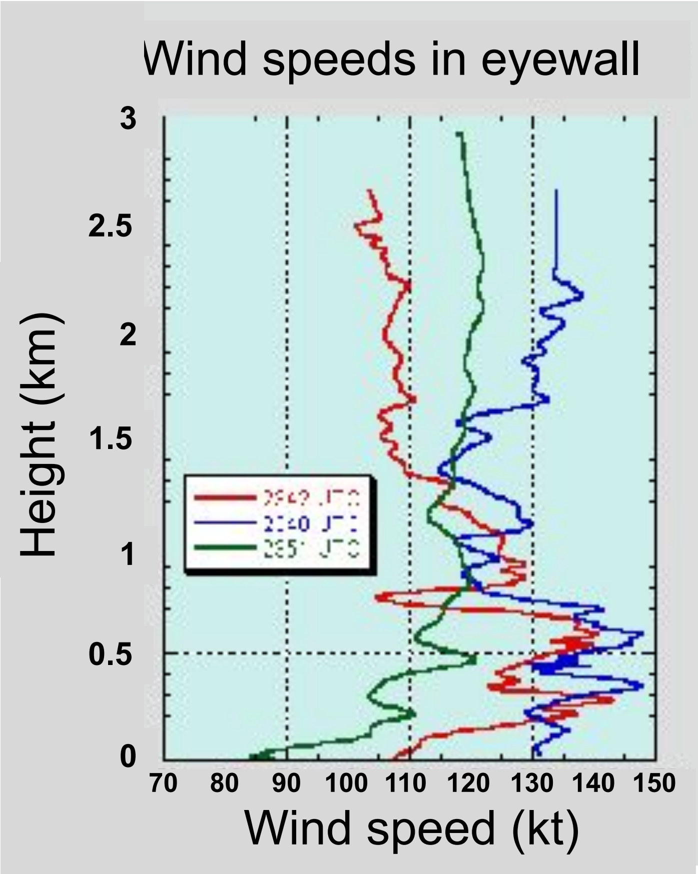
- Tail Doppler radar (TDR) onboard NOAA's P-3 and G-IV aircraft
- Fore–aft scanning technique (FAST) allows 3-D analyses of TC wind field
- Observations undergo an automated quality control process
- Analyses ready within 20 minutes



Current airborne observations - Instruments

GPS dropsonde

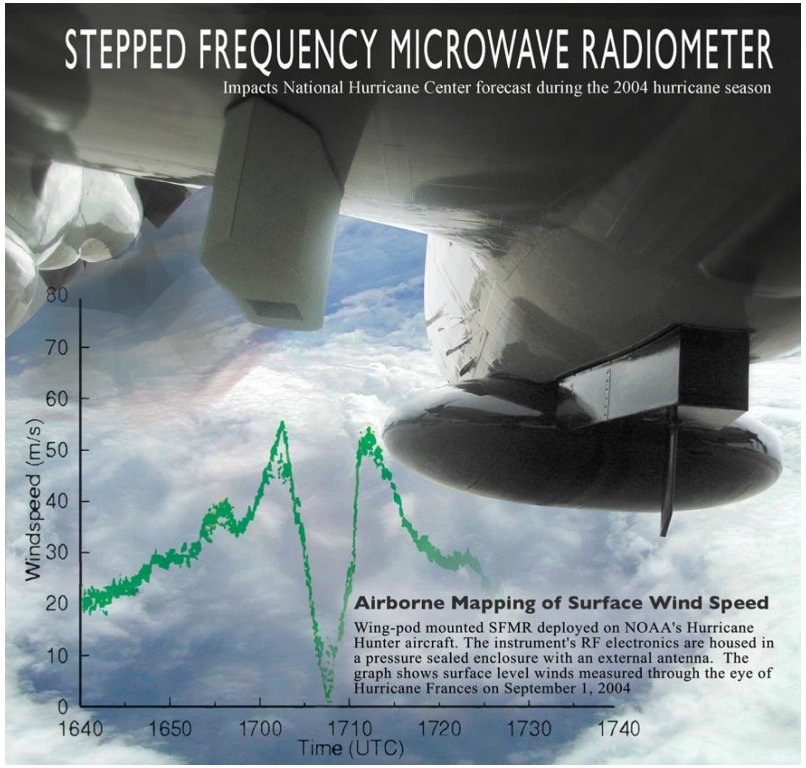


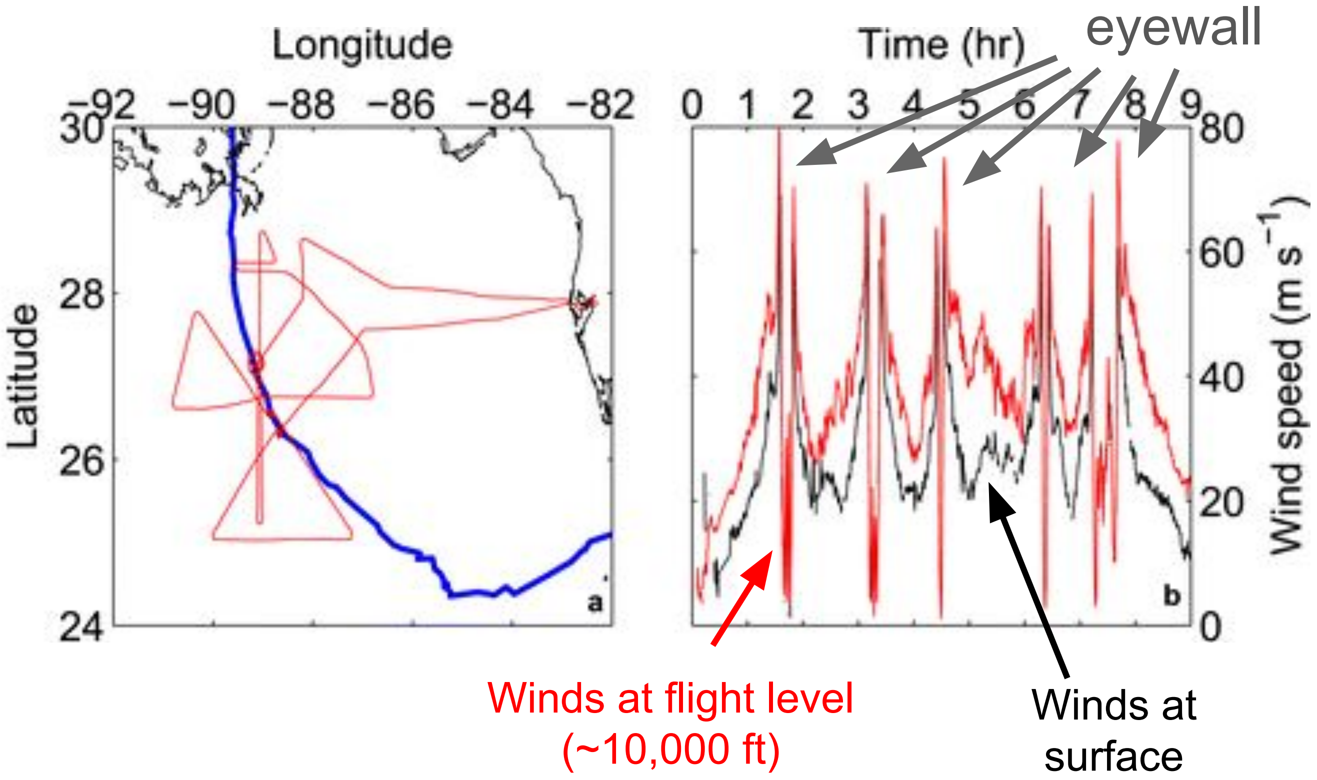


- Uses GPS for accurate wind speed and direction
- High-frequency 4 Hz sampling
- Cat-5 wind speeds in lowest 1500 ft

Current airborne observations - Instruments

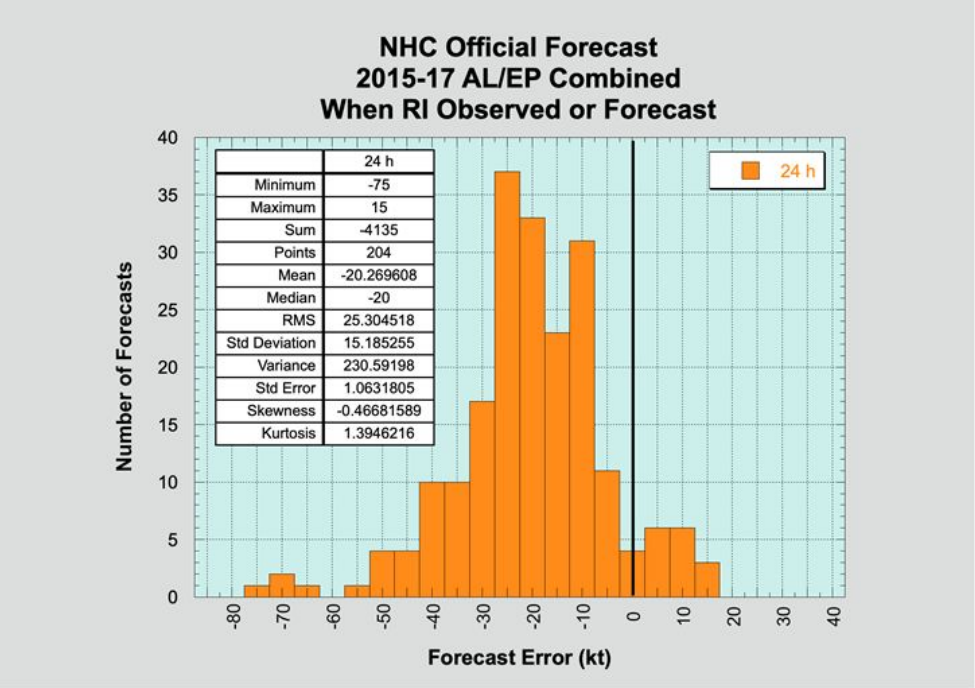
Stepped Frequency Microwave Radiometer (SFMR)

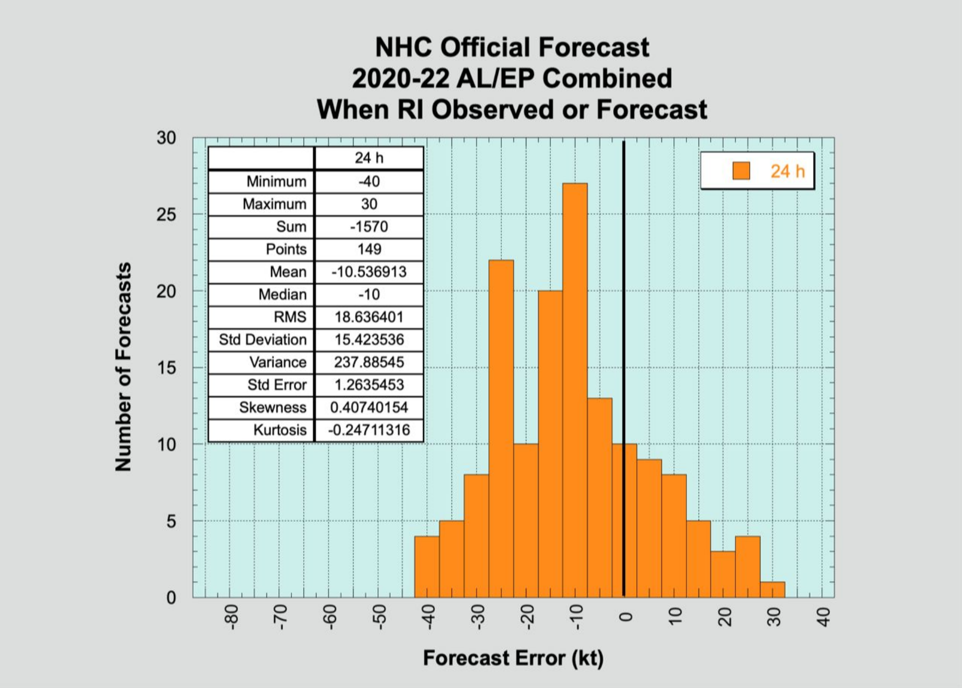




Winds at surface usually weaker than winds at flight level

Improving forecasts of Rapid Intensification





Courtesy: Robbie Berg, NHC

- NHC's 24-h intensity error during rapid intensification events cut in half since 2017 – 10 kt compared to 20 kt
- Largest under-forecast error reduced by 46% (40 kt compared to 75 kt)
- Forecast improvement partially contributed by aircraft observations that have improved models, data assimilation, and understanding of physical processes

Toward the future

New Research Foci

- Over the past several years there have been *multiple billion dollar TC-related disasters* (NOAA/NCEI)
- Storm-surge inundation, extreme rainfall, high surf, and tornadoes are significant contributors to damage, in addition to high winds
- Water (inland flooding from rainfall and surge) are responsible for most deaths (Rappaport 2000)
- Highlights the importance of **hazards**

Storm (Year)	Landfall Location	Rainfall [in]	Surge Inundation [ft]	Wind [kt]	US Tornadoes
Matthew (2016) [1]	Haiti	**23.80**	Unknown	**130**	2
	Cuba	**26.40**	13	**115**	
	Bahamas	19.70	8	**115**	
	South Carolina	18.95	7.7	75	
Harvey (2017) [2]	Barbados	Unknown	Unknown	40	52
	St. Vincent	Unknown	Unknown	40	
	Texas#	**60.58**	10	**115**	
Irma (2017) [3]	Barbuda	Unknown	8	***155***	25
	St. Martin	Unknown	Unknown	***155***	
	British V. I.	Unknown	Unknown	***155***	
	Bahamas	Unknown	Unknown	**135**	
	Cuba	**23.90**	10	***145***	
	Florida Keys	6–10	8	**115**	
	Marco Island, FL	**21.66**	10	**100**	
Maria (2017) [4]	Dominica	**22.80**	Unknown	***145***	3*
	Puerto Rico	**37.90**	9	**135**	
Florence (2018) [5]	North Carolina	**35.93**	11	80	44
Michael (2018) [6]	Florida	11.45	14	***140***	16
Dorian (2019) [7]	Barbados	Unknown	Unknown	45	21
	St. Lucia	Unknown	Unknown	45	
	St. Croix	Unknown	Unknown	65	
	St. Thomas	Unknown	Unknown	70	
	Bahamas^	**22.84**	20+	***160***	
	North Carolina	15.21	7	85	

Zawislak et al. 2021

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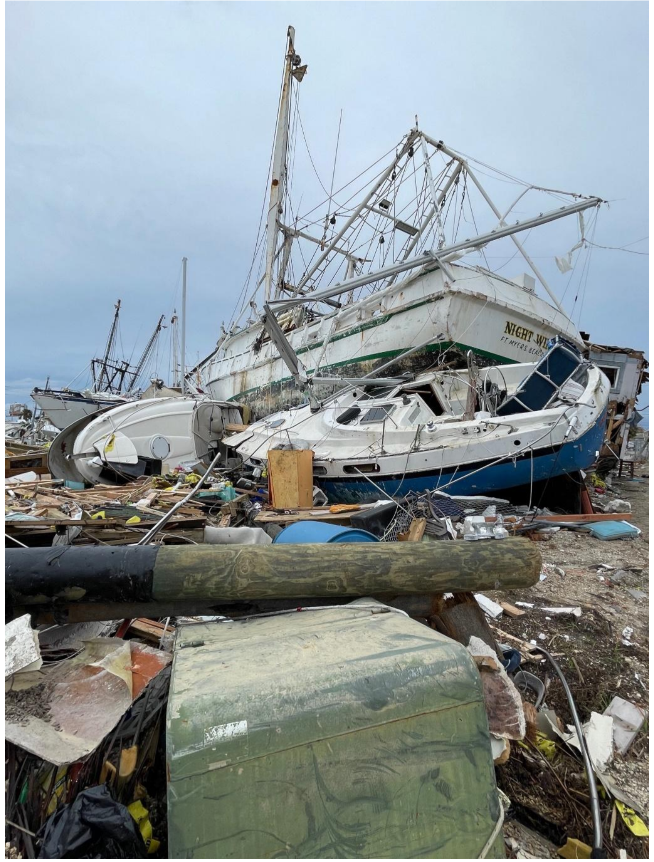
Toward the future

Damage from Hurricane Ian (2022) storm surge



Courtesy: Robbie Berg, NHC

Toward the future

Airborne observational priorities

Capability Prioritization

Priority	Capability	Sensor Number
1	Swath of surface wind vectors (not just a point)	2, 7, 14, 18
2	3-Dimensional wind speed and direction including clear air (Vertical, Meridional, and Zonal)	1, 4, 6, 7, 14, 19, 24
3	3-Dimensional Temperature and Moisture	6, 7, 8, 9, 10, 17
4	Boundary layer and below temperature, wind, turbulence, and moisture	6, 7, 8, 23
5	Sea Surface Temperatures	3, 10, 16
	Sub-Surface Ocean Structure (temp, currents, and salinity)	10, 11, 12, 13, 16
6	2-Dimensional Wave Spectra	1, 5, 15, 21, 25, 26
7	Microphysics above freezing level	1, 20, 22

Future platforms

New Airborne Platforms and Instruments fill observational gaps

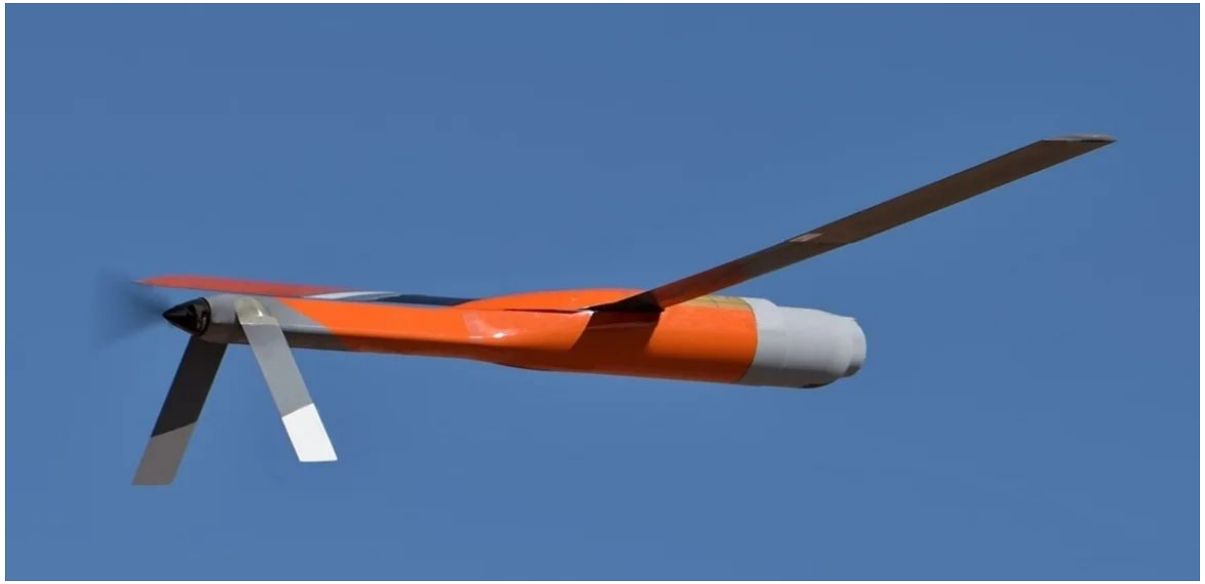
- G-IV at end of service life, will be retired in 2025
- G-550 will be acquired and ready for operations by summer 2025
- Higher ceiling, longer range than G-IV
- Potential 2nd G-550 will be acquired

- P-3's will no longer be supported by 2030
- Fleet of NOAA C-130's will be acquired, potentially 4

Future instruments

New Airborne Platforms and Instruments fill observational gaps

Uncrewed systems



Small uncrewed aerial system (sUAS)

Saildrone

- Can get measurements near, at, and below ocean surface, where crewed platforms can not reach

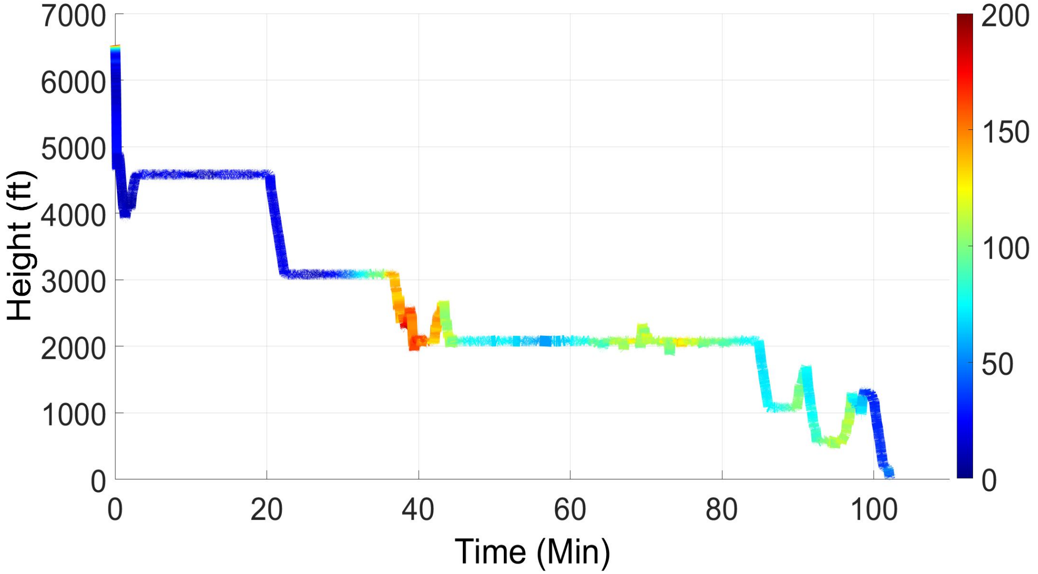
Future instruments

New Airborne Platforms and Instruments fill observational gaps

Small uncrewed aerial systems (sUAS)

Courtesy: Nick Underwood, AOC

- video of sUAS launch



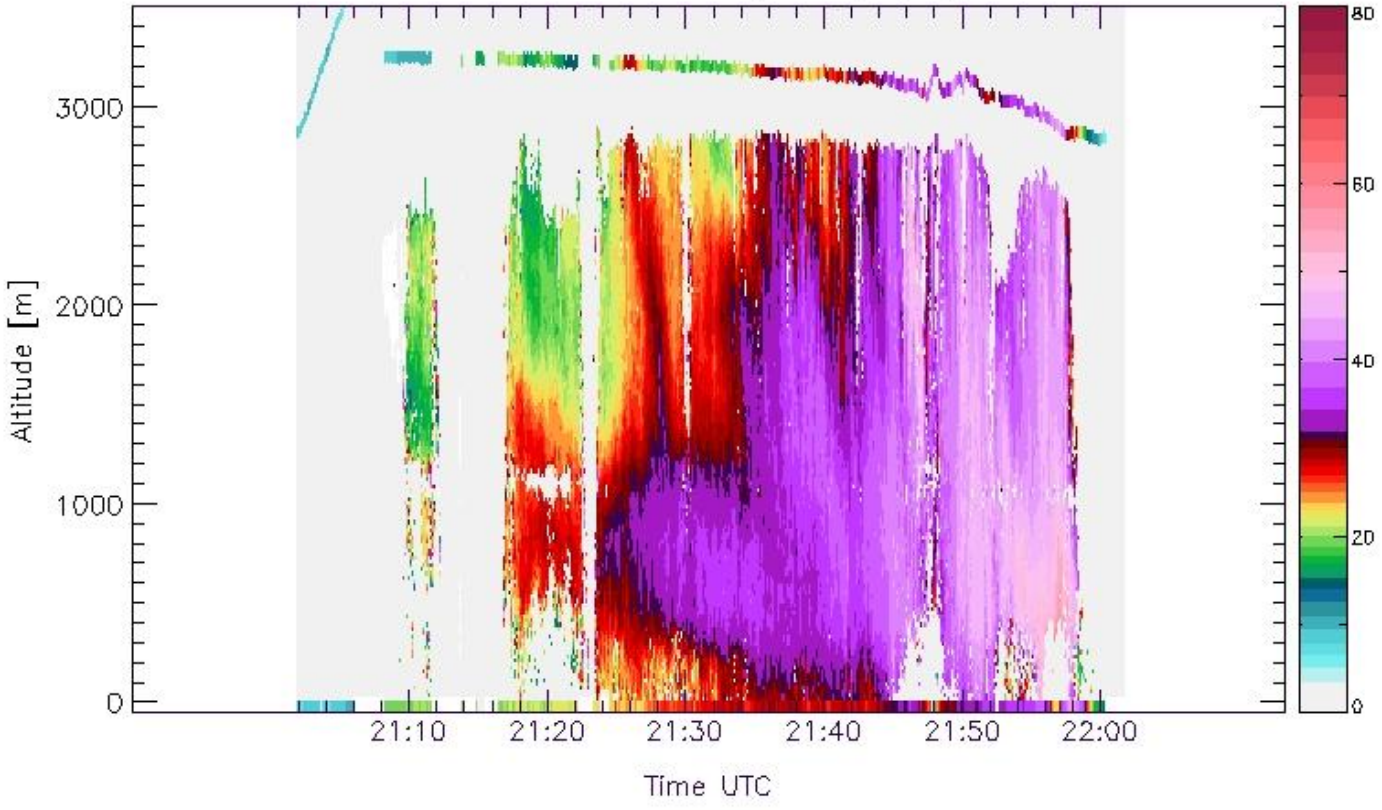
- Measured winds > 185 kt (215 mph) at ~2000 ft in western eyewall

Future instruments

New Airborne Platforms and Instruments fill observational gaps

Imaging Wind and Rain Airborne Profiler (IWRAP)

Horizontal wind speed (m/s) in Ian

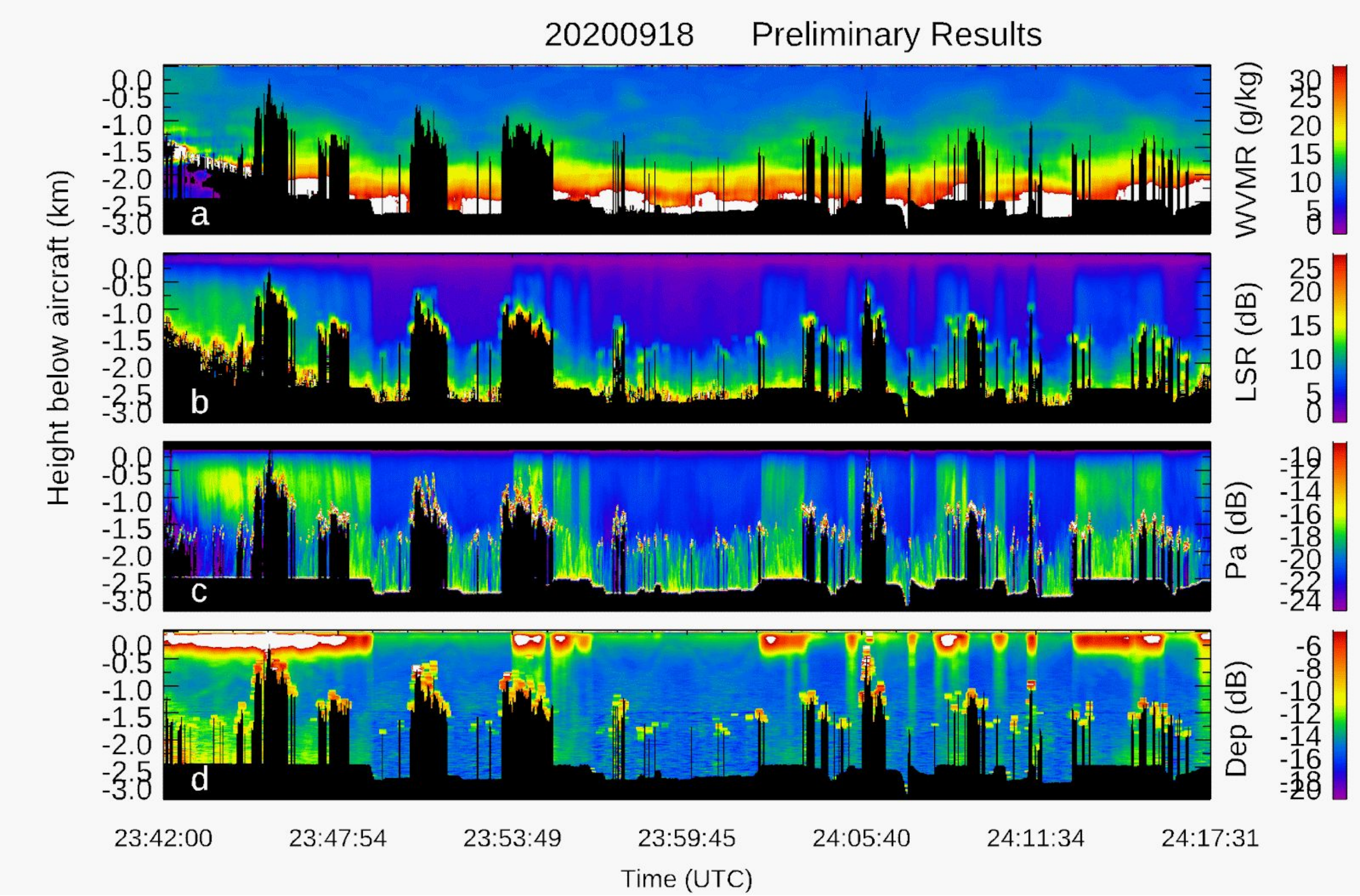


- Detailed measurements of wind speed in the lowest 3 km of atmosphere

Future instruments

New Airborne Platforms and Instruments fill observational gaps

Compact Raman Lidar (CRL)



- Lidar retrievals of three-dimensional fields of temperature, water vapor, clouds, and aerosols below flight level
- 45 m vertical, 100-1000 m horizontal resolution
- Provide valuable thermodynamic information in boundary layer

Future instruments

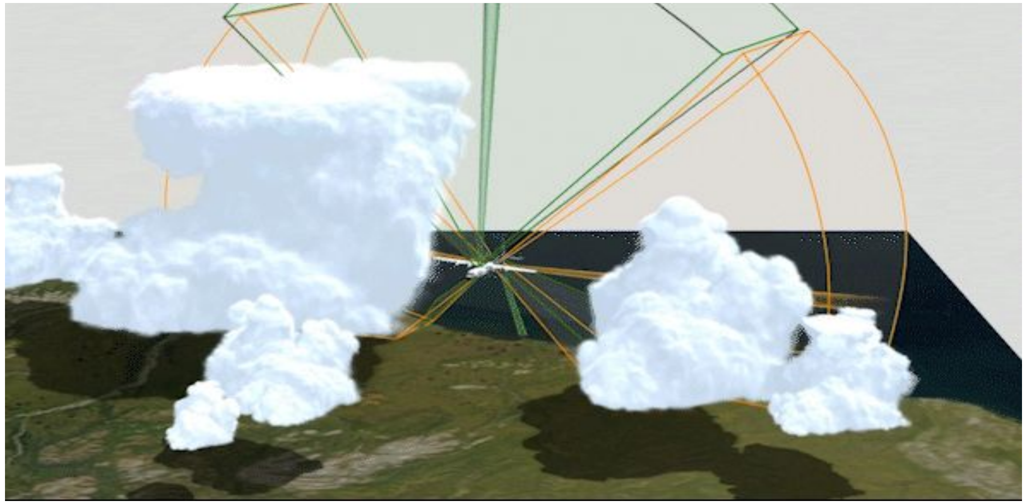
New Airborne Platforms and Instruments fill observational gaps

APAR: Airborne phased array radar

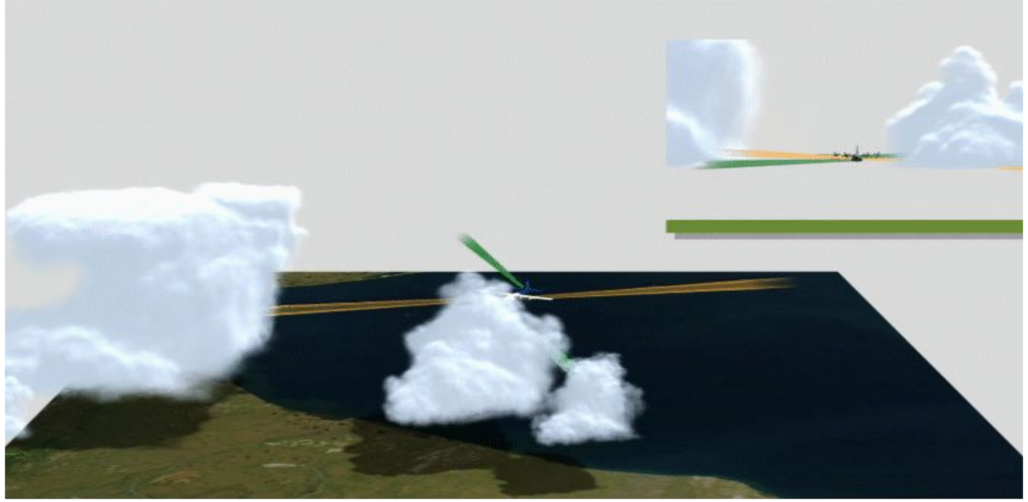
Courtesy: Wen-Chau Lee, NCAR

- Dual Horizontal/Vertical Polarization (Dual-Pol) technology
  - Observe microphysical properties of clouds & hydrometeors.
  - Critical real-time data to improve forecasts & understanding of TC intensity, extreme precipitation & severe convection.

Dual-Doppler & Dual-pol scanning



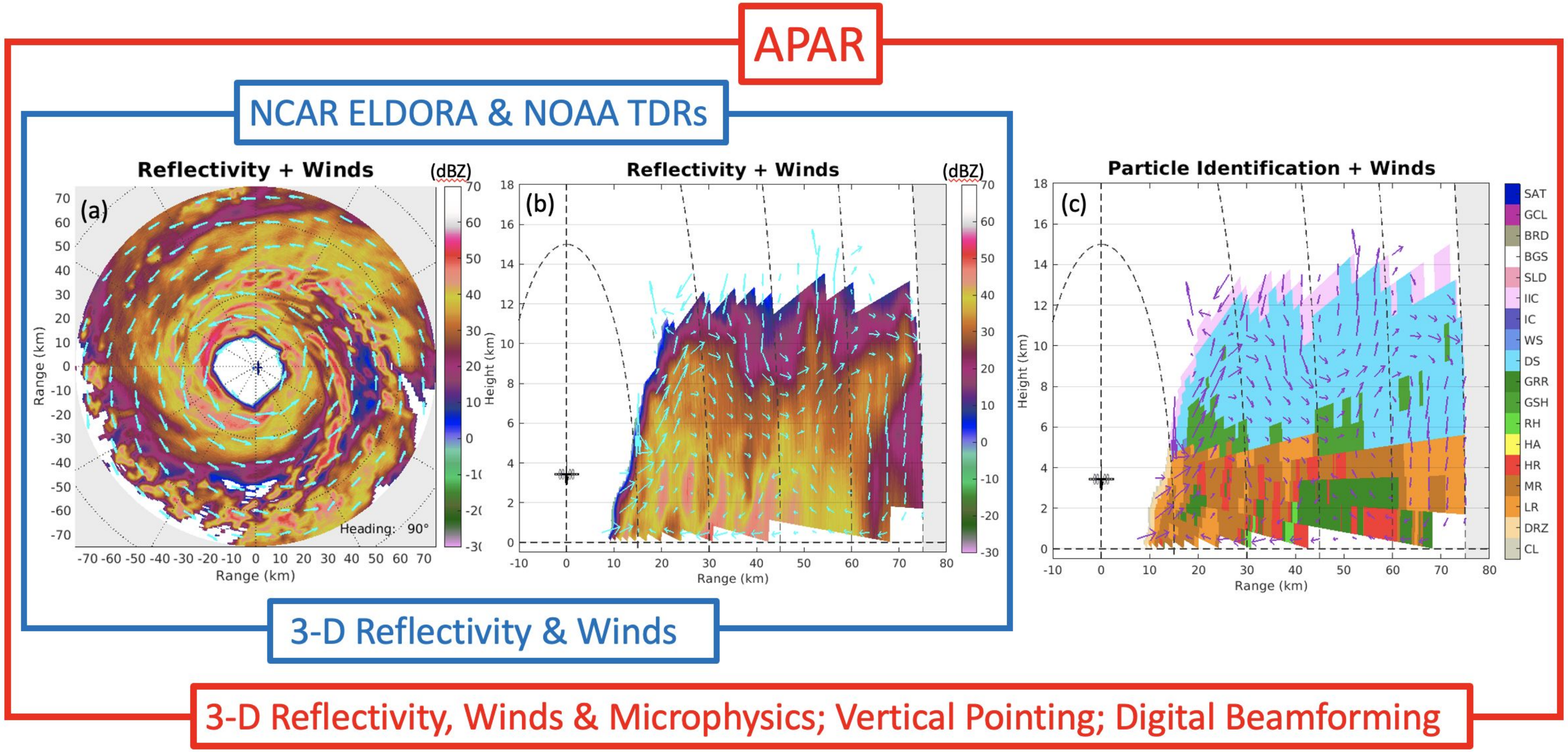
Surveillance scanning (APAR and C-130 nose radar)



Future instruments

New Airborne Platforms and Instruments fill observational gaps

APAR: Airborne phased array radar



Courtesy: Wen-Chau Lee, NCAR

- APAR adds measurements of hydrometeor type (rain, ice, snow, etc.)
- Helpful for model improvement, prediction of rainfall from hurricanes, possibly hurricane intensity

Summary

- Hurricane-penetrating aircraft have a long history of providing valuable information to forecasters and improving our understanding of physical proceses
- More recent applications of aircraft data have helped to improve computer model and NHC predictions of hurricane intensity and rapid intensification
- Emphasis now is shifting toward improving predictions of hurricane hazards (surge, rainfall, severe weather)
- New instruments and platforms coming online, or expected to come online, offer hope of filling many of the observational gaps that currently exist

Inside a hurricane eye

NOAA's Atlantic Oceanographic and Meteorological Laboratory
U.S. Department of Commerce

THANK YOU

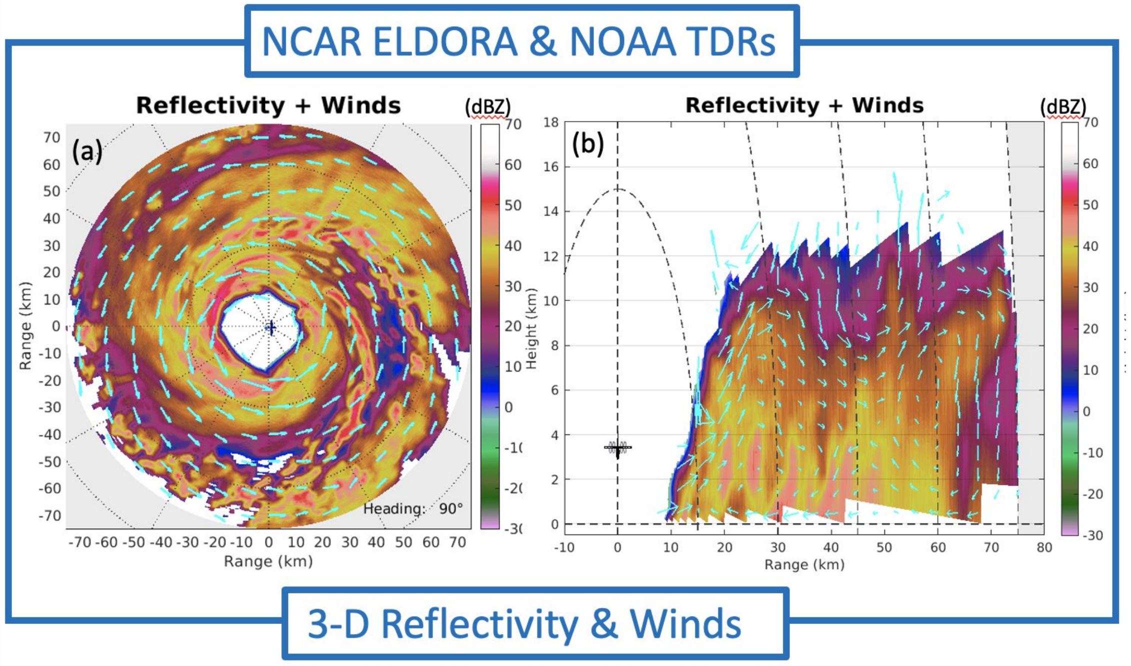
QUESTIONS?

(Robert.Rogers@noaa.gov)

Future instruments

New Airborne Platforms and Instruments fill observational gaps

APAR: Airborne phased array radar



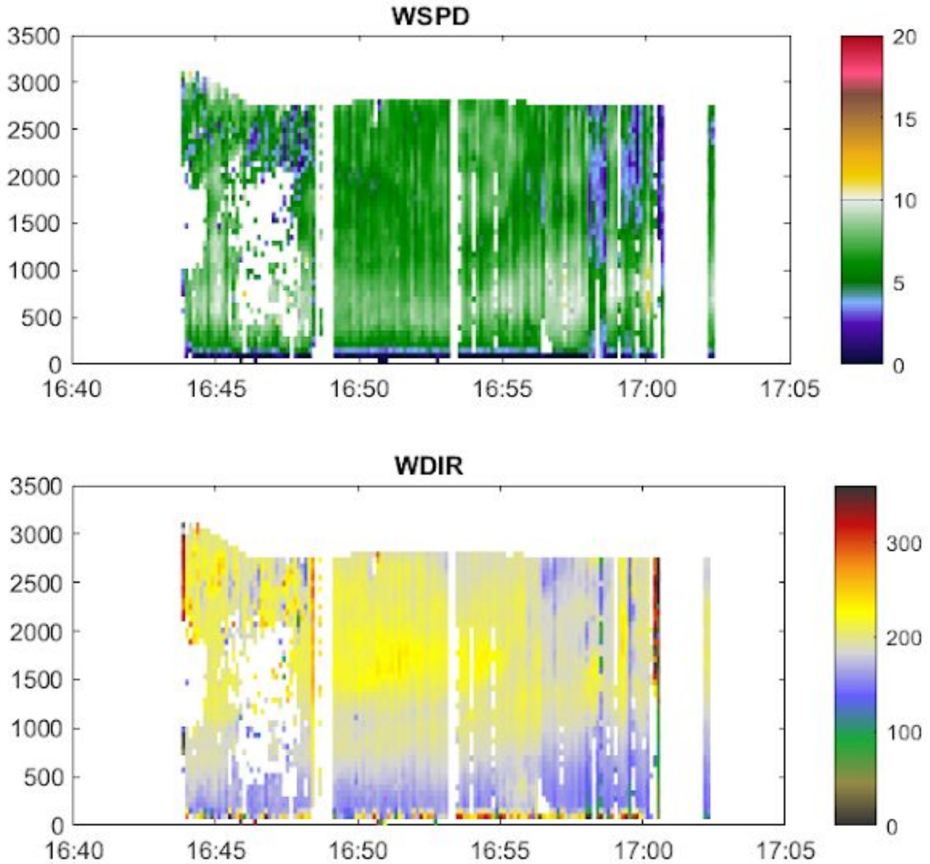
Courtesy: Wen-Chau Lee, NCAR

- Current airborne radars provide capability to measure reflectivity and winds

Future instruments

New Airborne Platforms and Instruments fill observational gaps

Micro-Pulse Doppler (MicroDop) Lidar



- Lidar retrievals of three-dimensional fields of winds and aerosol backscatter below flight level
- Complements tail Doppler radar by providing winds in absence of precipitation scatterers