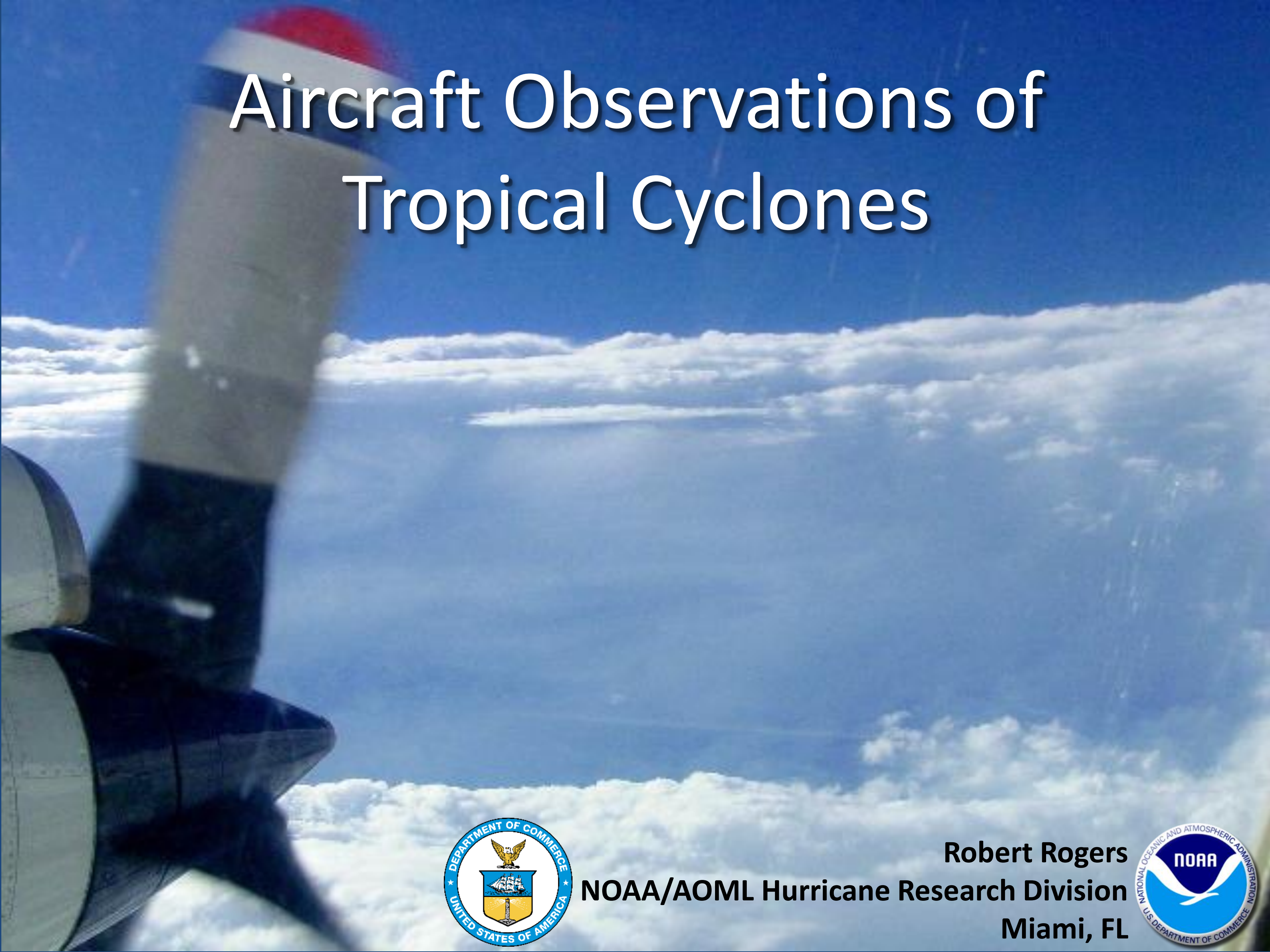


Aircraft Observations of Tropical Cyclones

Robert Rogers
NOAA/AOML Hurricane Research Division
Miami, FL

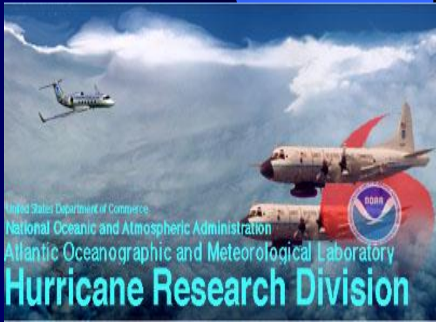
Motivation

Why are observations important?

- Many important physical processes within hurricanes span scales that cover many orders of magnitude, ranging from thousands of kilometers to millionths of meters
- Observations can span these scales, and are a key component of a balanced approach toward advancing understanding and improving forecasts of hurricanes (observations, modeling, theory)
- Provide real-time information on TCs, assess performance of models, and provide a check on theories
- Three primary platforms for observations –

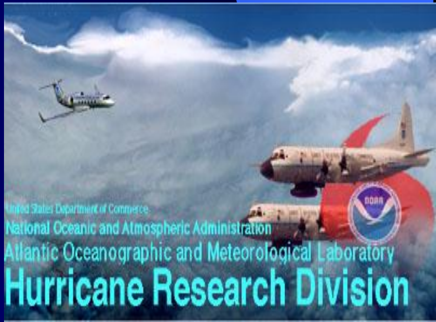
  airborne, spaceborne, and land-based

  -- focus here on airborne



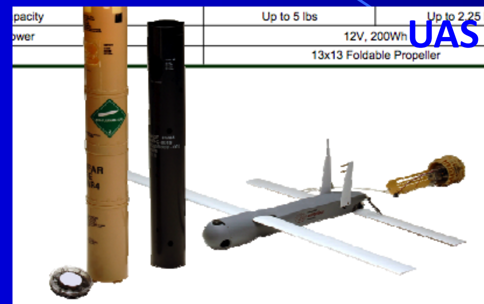
Outline

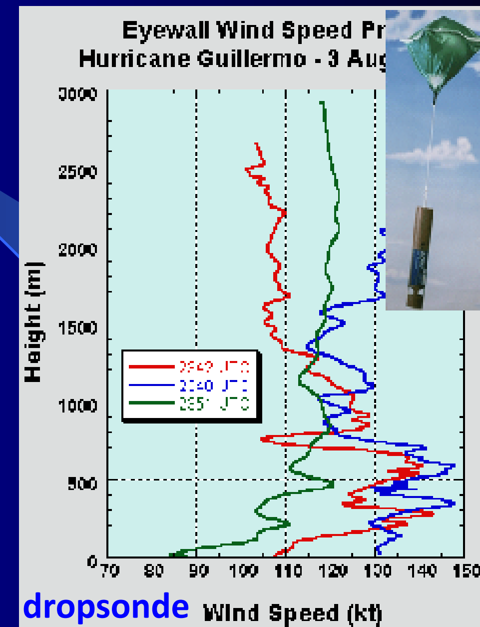
1. Tools for observing hurricanes
2. Use of observations to improve hurricane forecasts
3. Flight profiles
4. Views from the aircraft



1. Tools for observing hurricanes

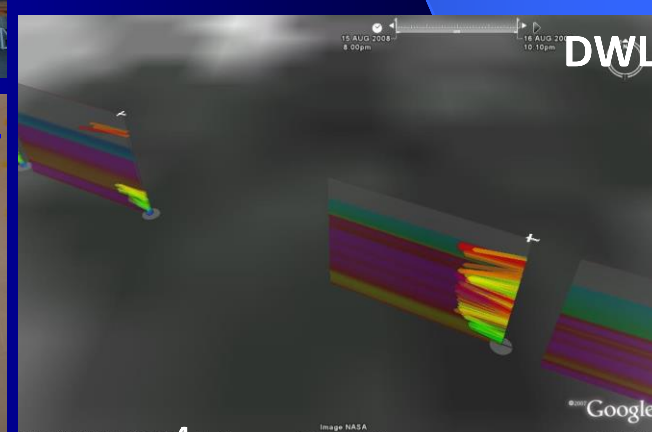
- **In-situ**
  - Wind, press., temp.





- **Expendables**
  - Dropsondes
  - AXBT, AXCP, buoy

- **Remote Sensors**
  - Tail Doppler Radar (TDR)
  - SFMR
  - Doppler Wind Lidar (DWL)
  - Scanning Radar Altimeter
  - Scatterometer/ profiler
- **Platforms**
  - Unmanned Aerial Systems (UAS)



Tools for observing hurricanes

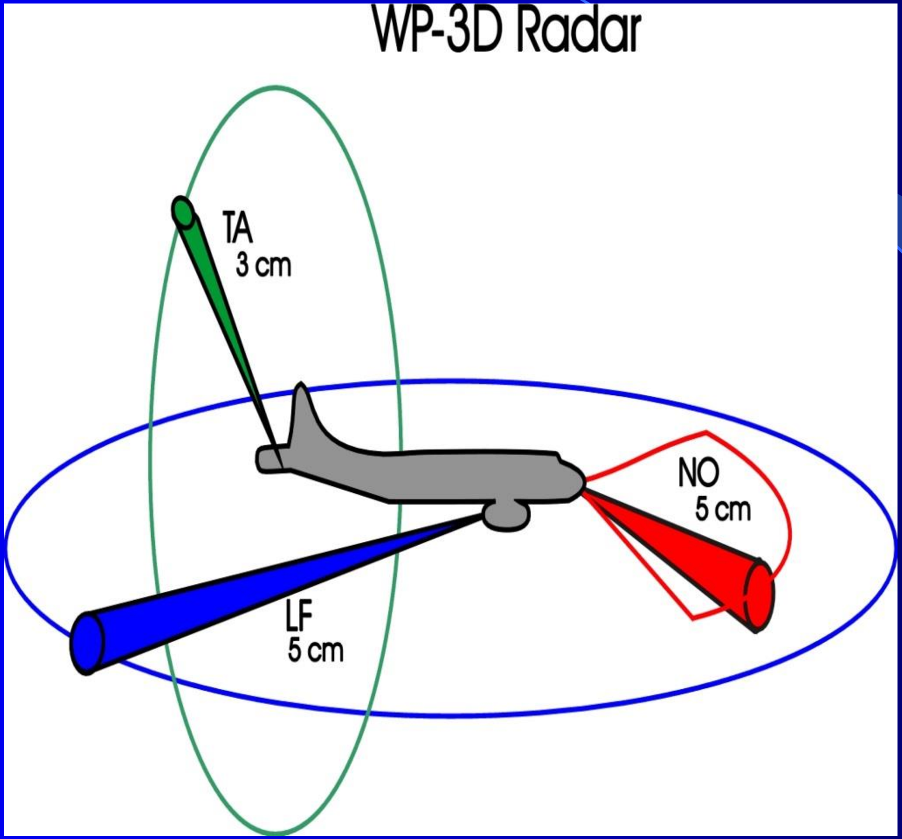
“Miss Piggy” Built in 1976 at Lockheed-Martin, Marietta, Georgia

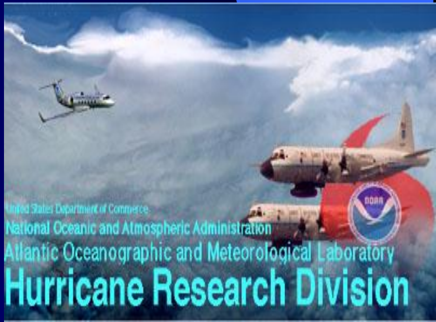
“Kermit” Built in 1975 at Lockheed-Martin, Marietta, Georgia

“Gonzo” Built in 1994 at Gulfstream Aerospace Corporation in Savannah Georgia

Airborne radar

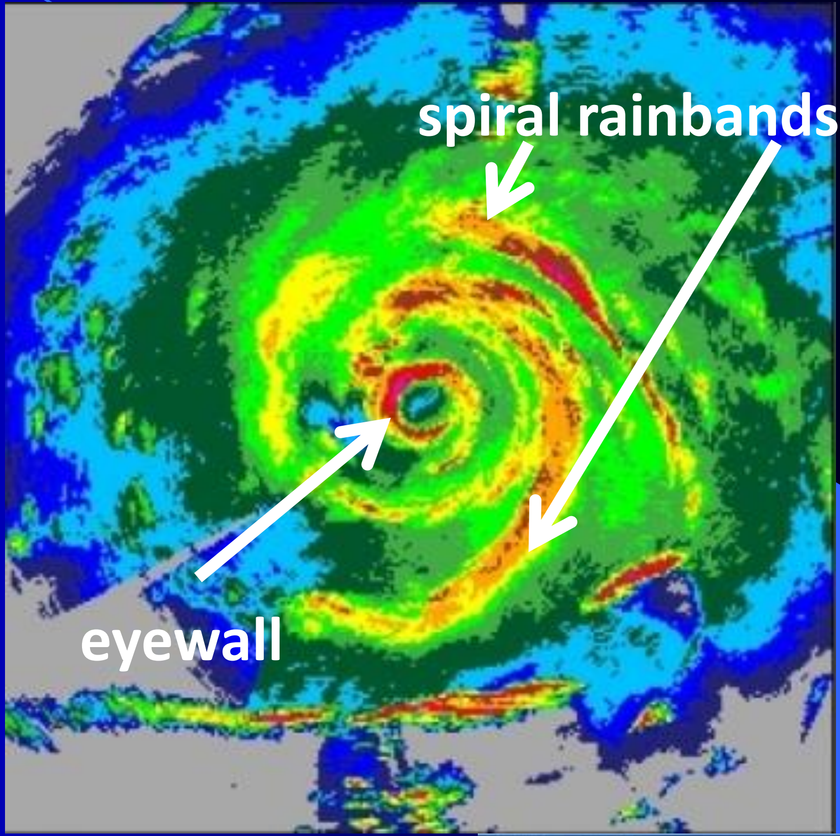
Radars on WP-3D

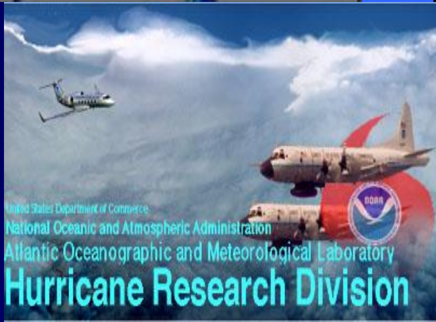




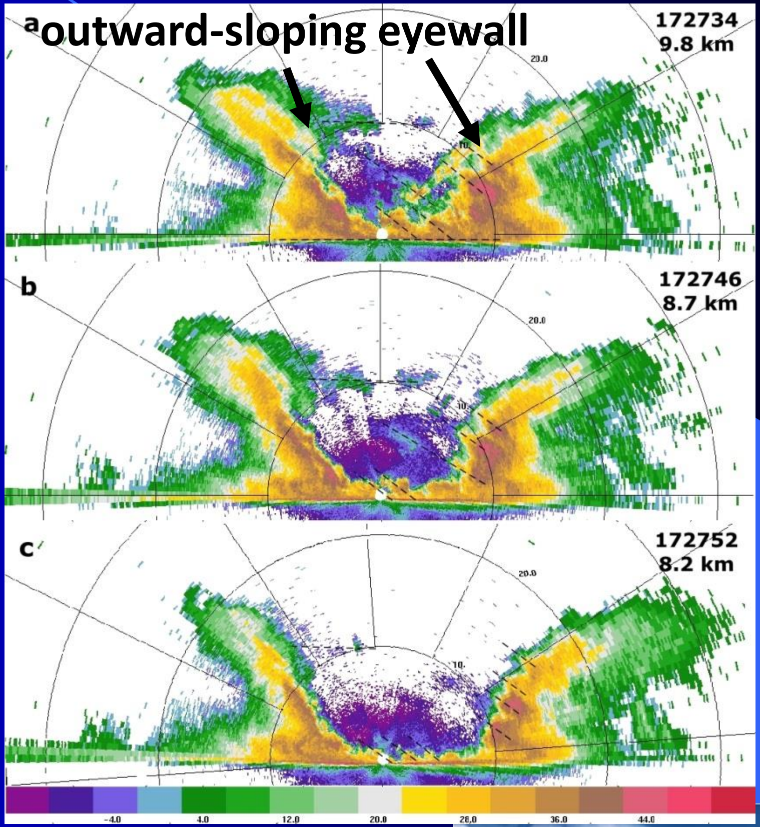
Lower Fuselage (LF) Radar

LF image of Hurricane Ivan (2004)

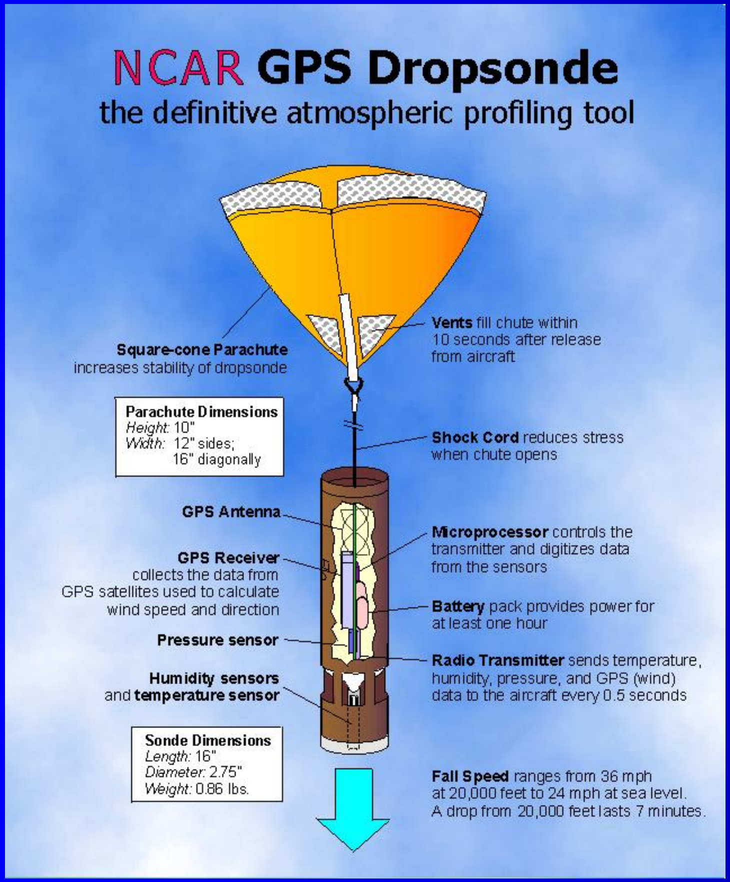


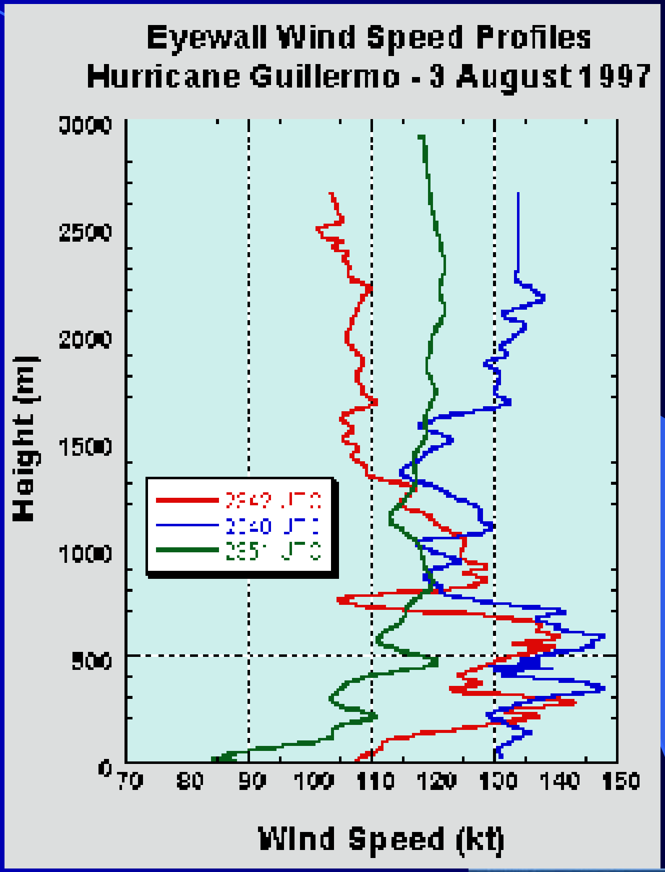


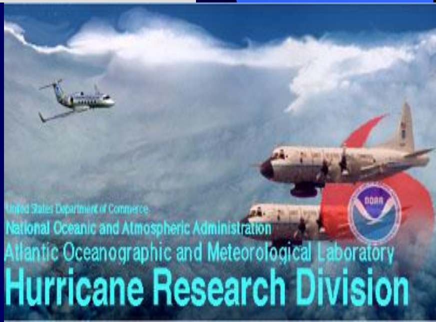
Tail Doppler Radar



GPS dropsonde



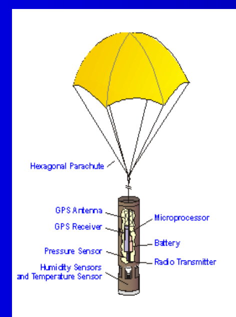


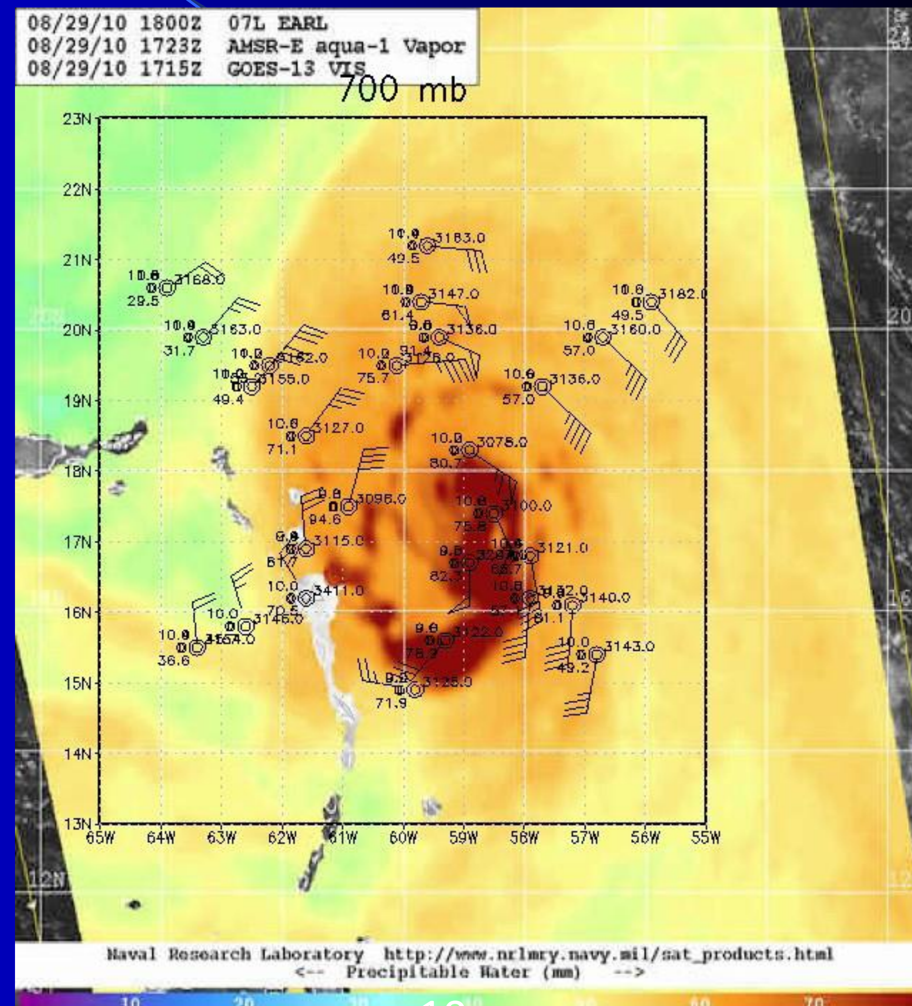


Scales sampled by Airborne Observations

Environmental structure

- Synoptic-surveillance using dropsondes





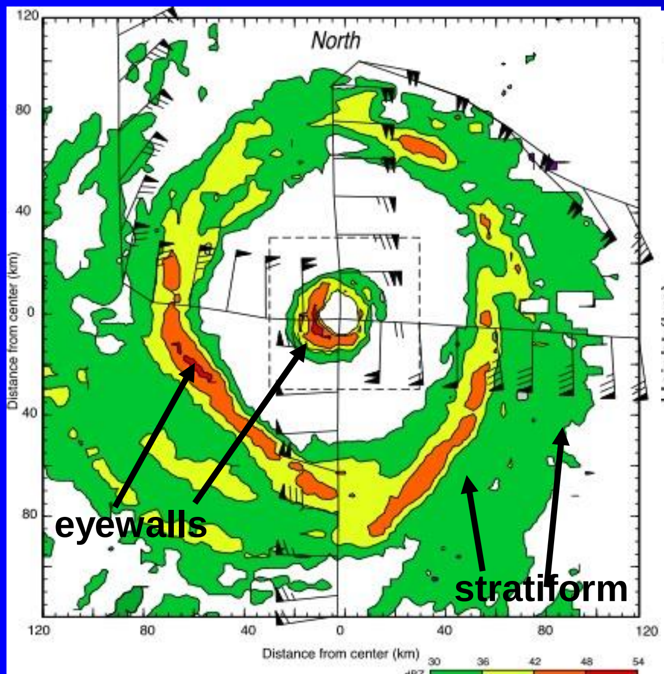
- Steering flow
- Variation in moisture content of environment around hurricane

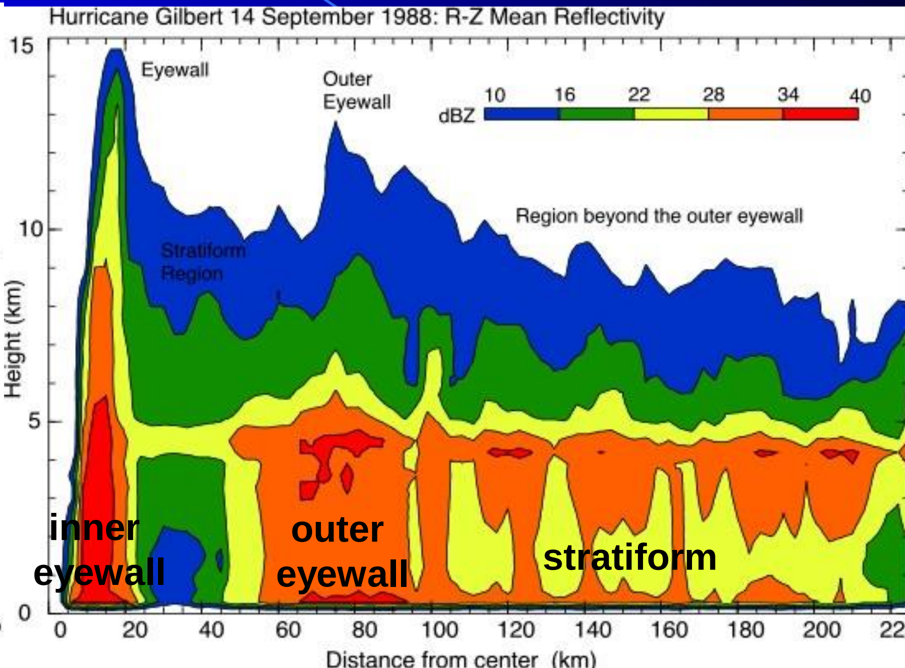
Hurricane Research Division

Scales sampled by Airborne Observations

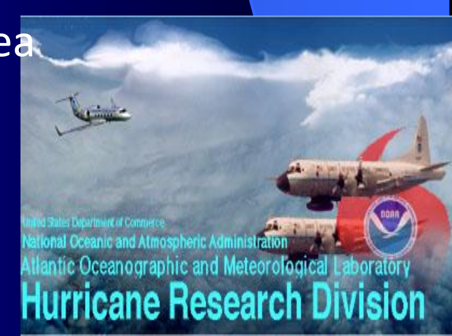
Vortex Structure

Double eyewalls seen from airborne radar





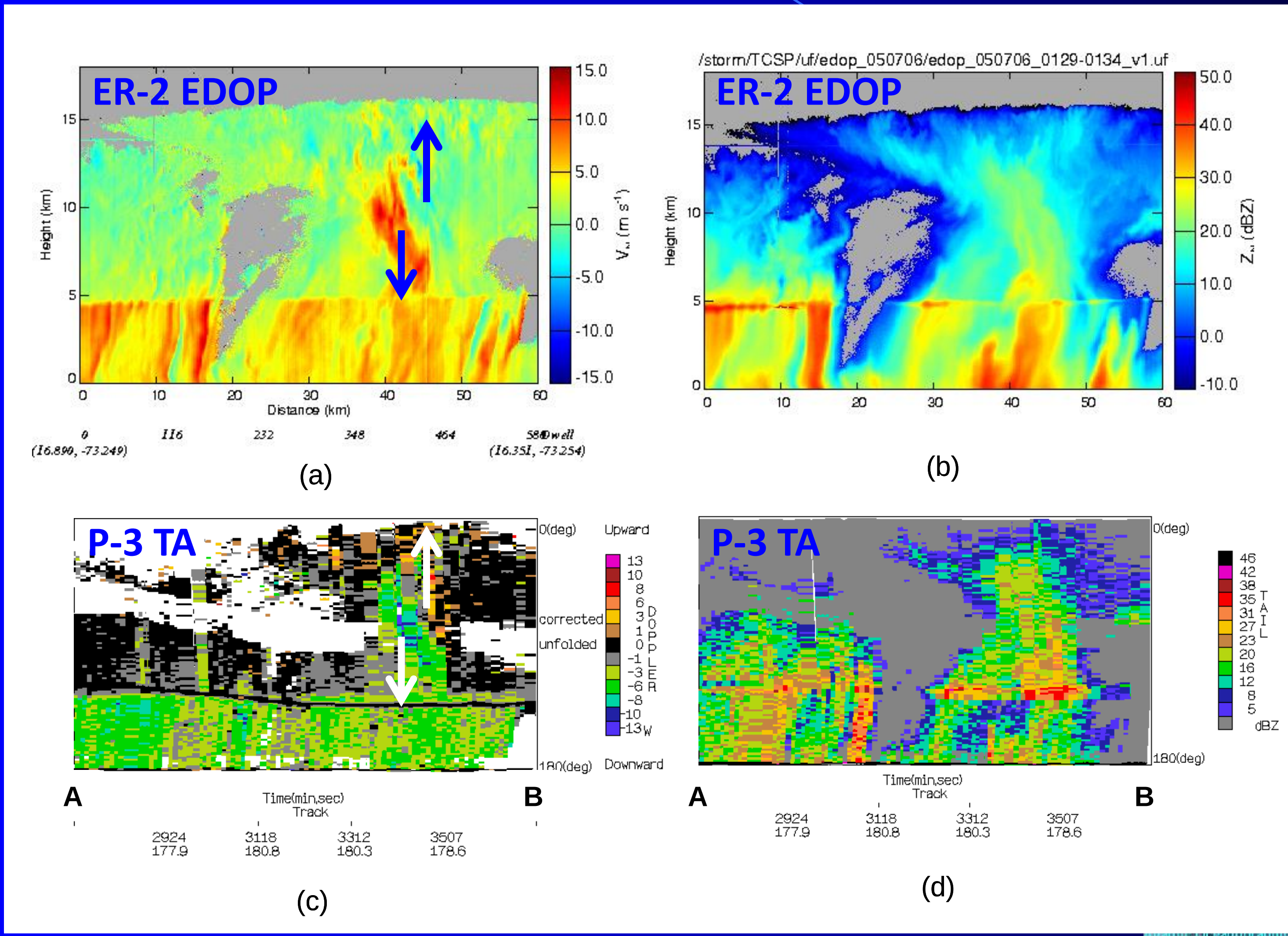
- Highest rain rates normally in eyewall, mostly convective, cover small area
- Lighter rain rates in stratiform areas outside eyewall, cover larger area



Scales sampled by Airborne Observations

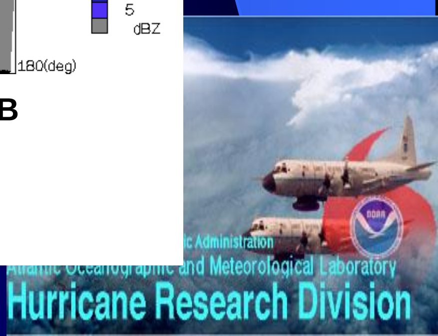
Convective Structure

Strong convection seen from radar



Vertical velocity (m/s)

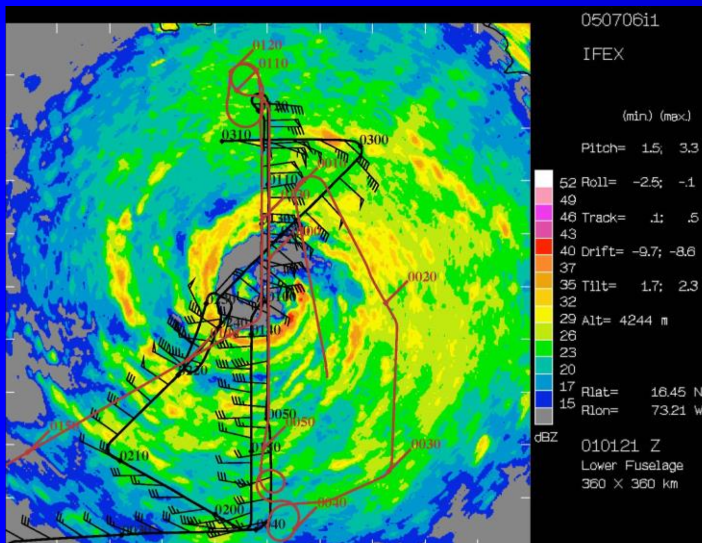
Reflectivity (dBZ)



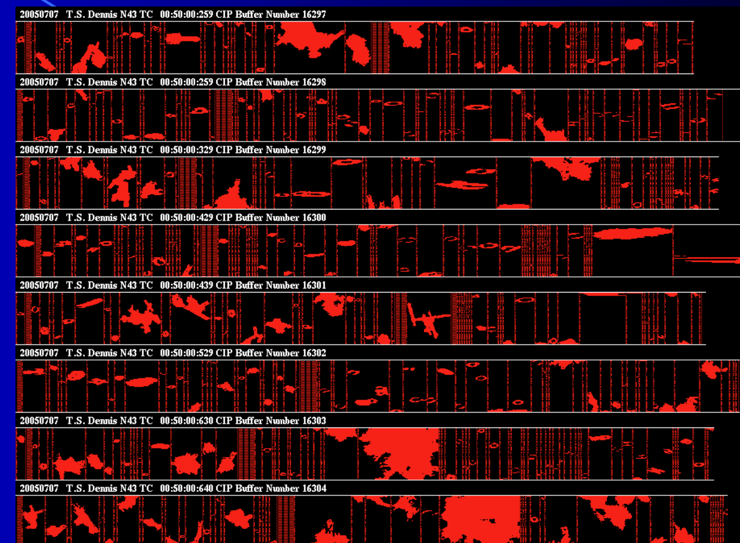
Scales sampled by Airborne Observations

Microphysical Structure

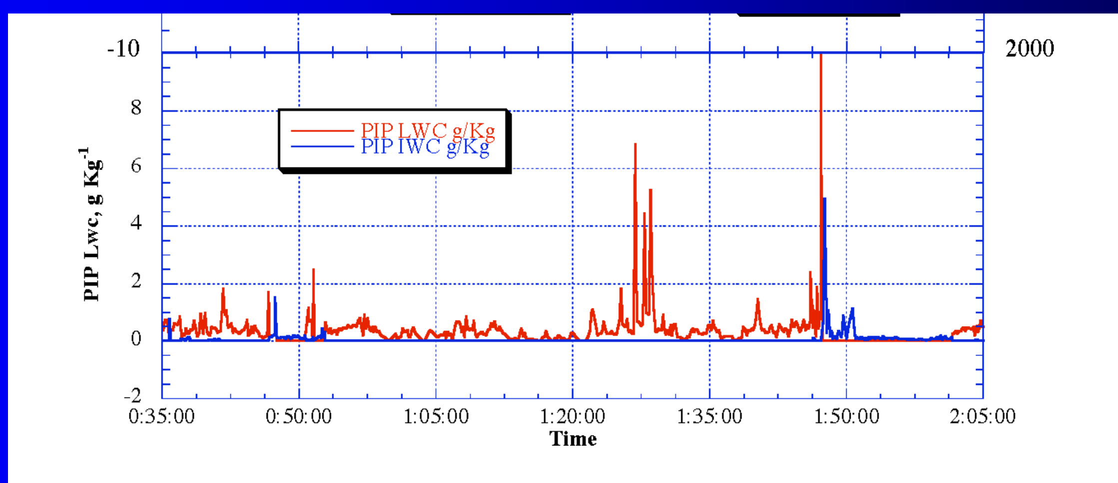
Flight track and LF image

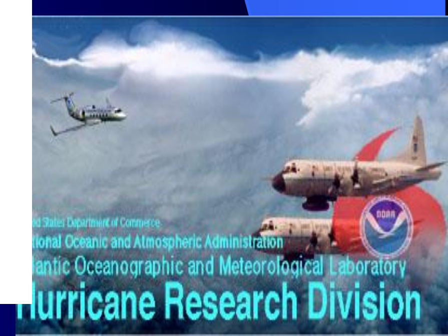


Cloud physics particle images



Concentration of cloud physics (ice and water) particles





New Airborne Platforms

Global Hawk Aircraft (Unmanned Aerial System)

- can stay airborne for >24 h, compared with 8 h for P-3 and G-IV

First Global Hawk landing at Wallops Flight Facility, Sept. 7, 2012.

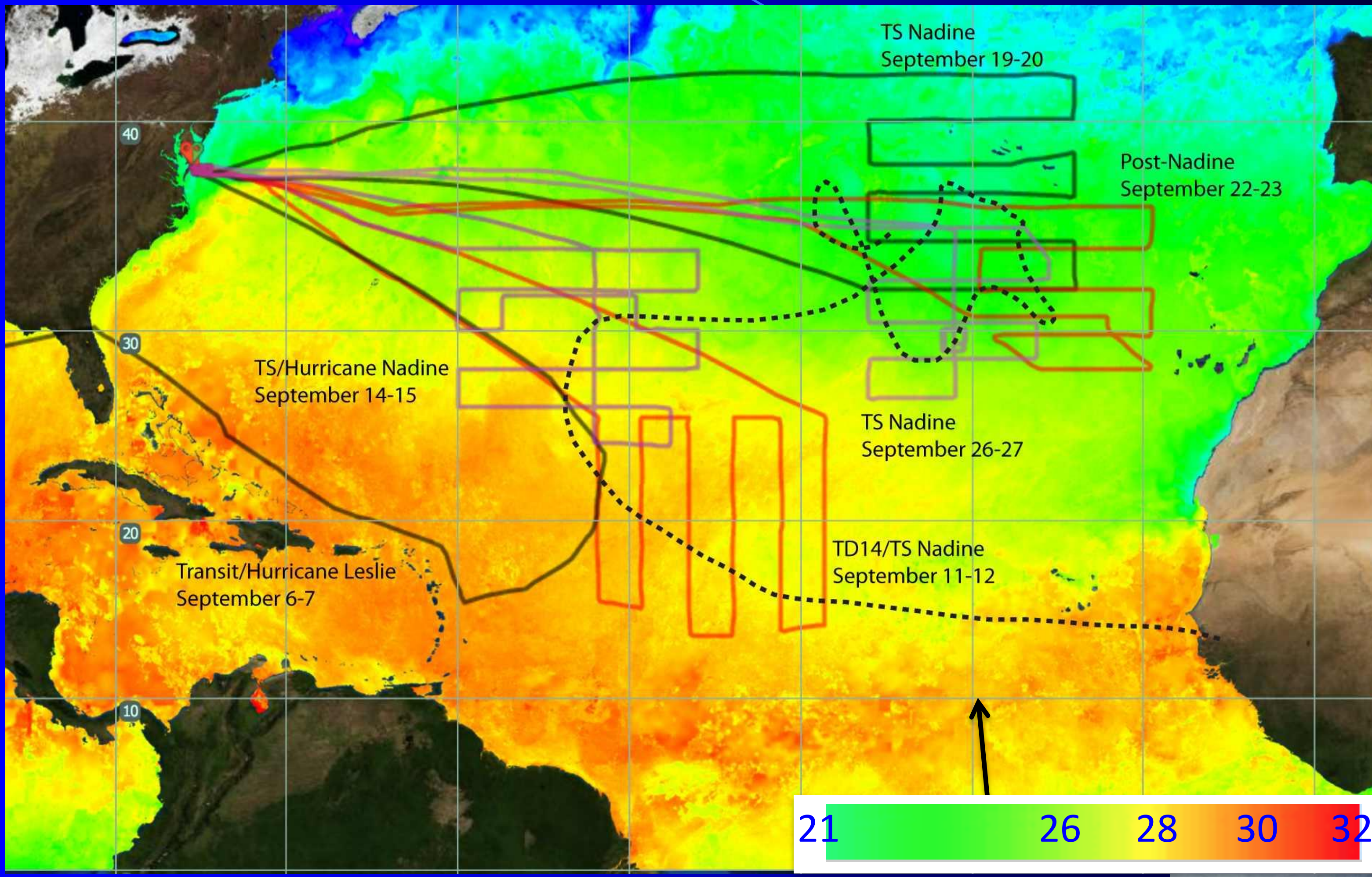
New Airborne Platforms

Global Hawk Operations Center (NASA Armstrong Base, CA)

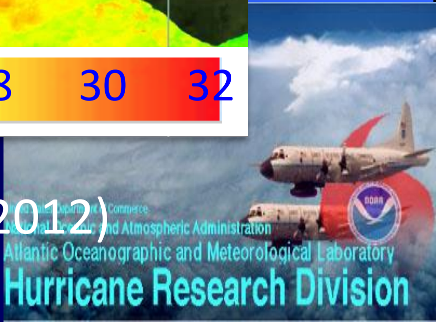
United States Department of Commerce
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
Hurricane Research Division

New Airborne Platforms

Long range of Global Hawk



(Hurricane and Severe Storm Sentinel, HS3, from 2012)

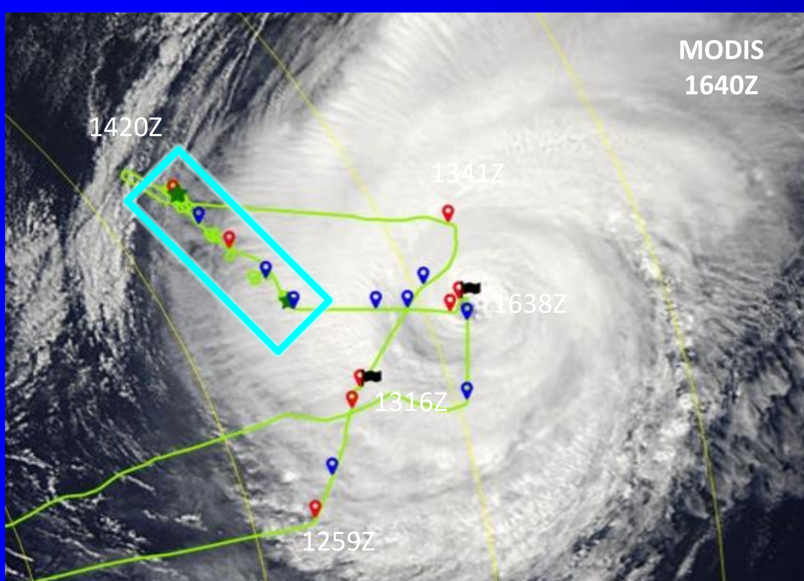


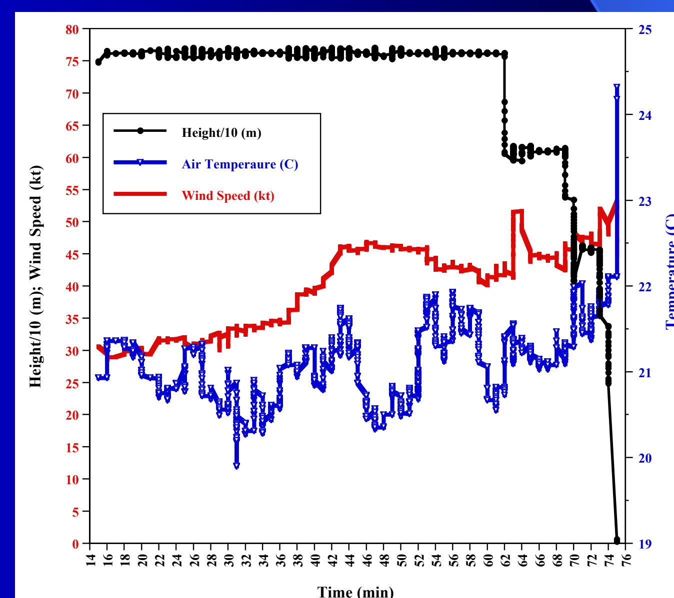
New Airborne Platforms

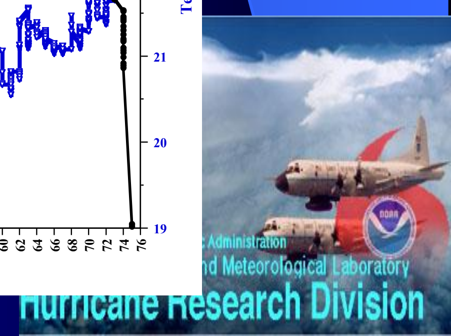
Coyote (Unmanned Aerial System)

- released from P-3 like a dropsonde, can be controlled for ~2 h
- can get measurements down to surface, where manned aircraft can not reach

Coyote measurements in Hurricane Edouard (2014)

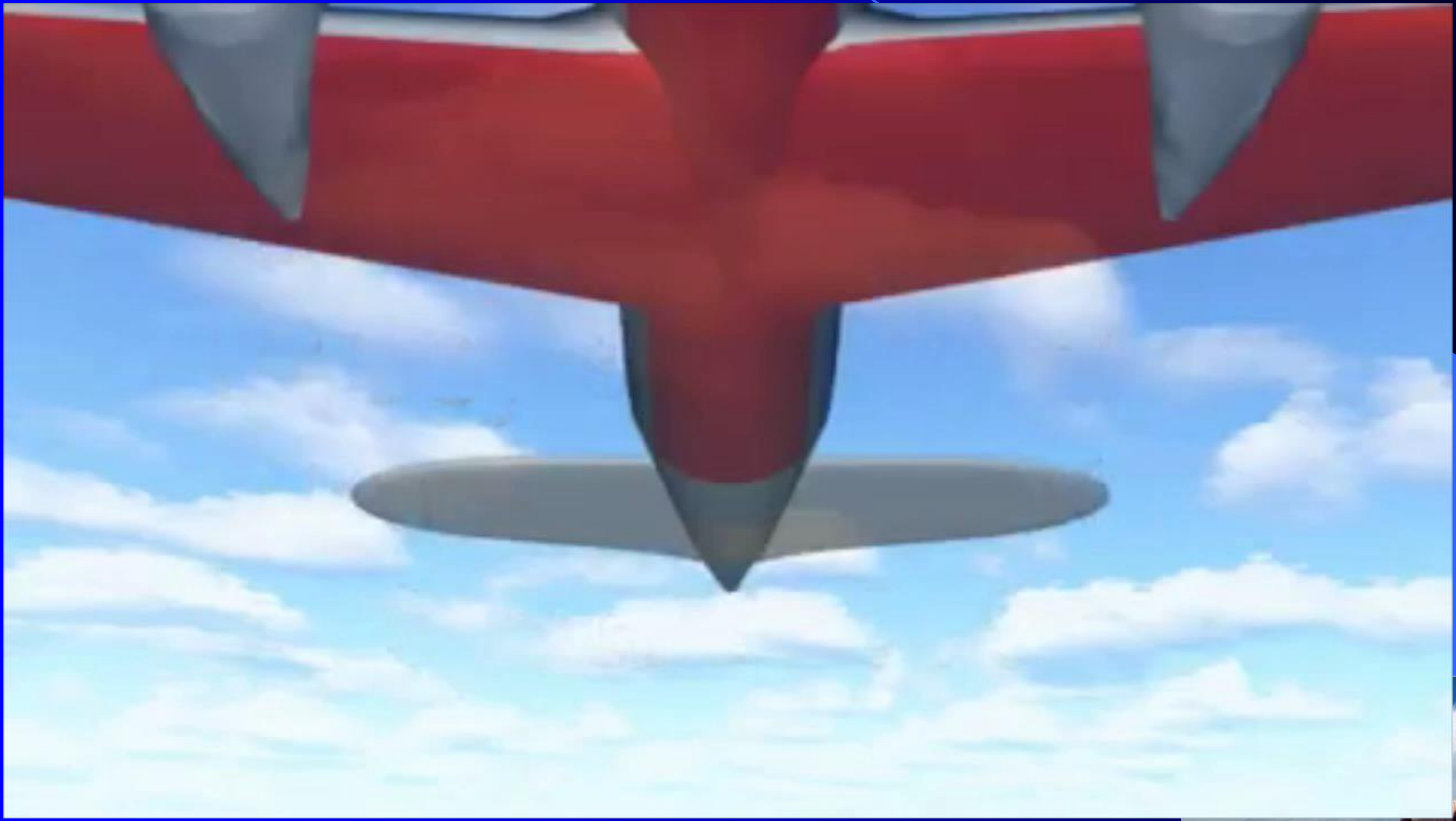






New Airborne Platforms

Depiction of Coyote launch



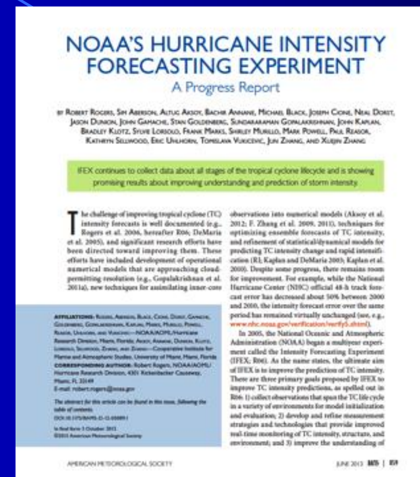
2. Use of observations to improve hurricane forecasts

Intensity Forecasting Experiment (IFEX)


THE INTENSITY FORECASTING EXPERIMENT

A NOAA Multiyear Field Program for Improving Tropical Cyclone Intensity Forecasts

Rogers et al., BAMS, 2006

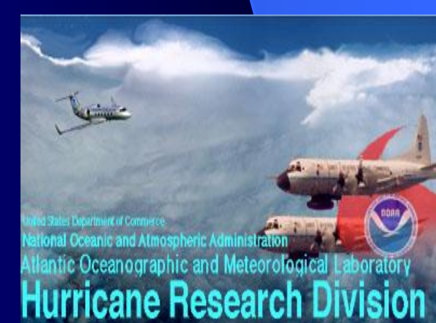

NOAA'S HURRICANE INTENSITY FORECASTING EXPERIMENT

A Progress Report

Rogers et al., BAMS, 2013

IFEX intended to improve prediction of TC intensity change by addressing <u>three goals</u>:

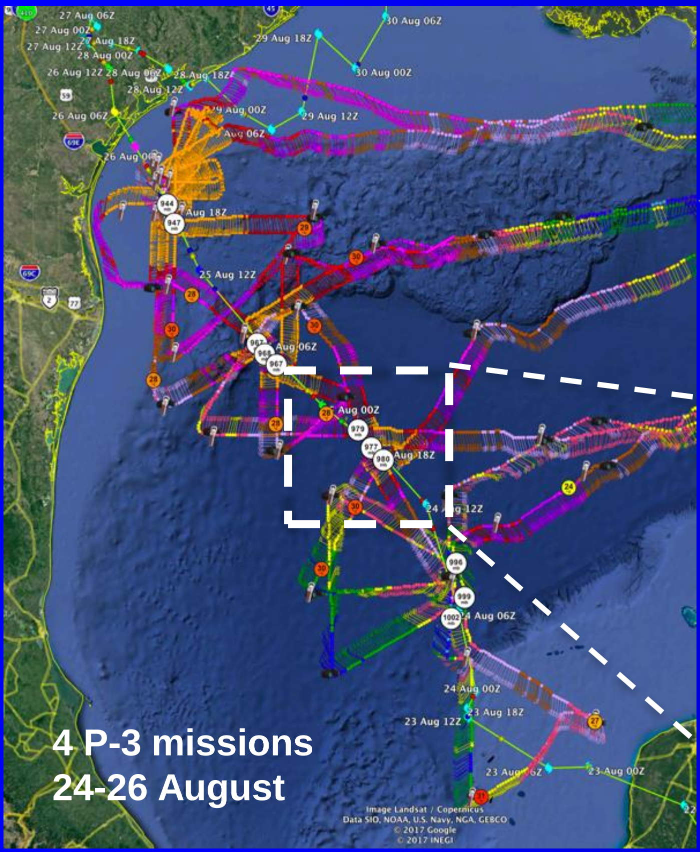
1) **FORECASTS**: Collecting observations that span TC life cycle across scales for model initialization, evaluation
2) **NOWCASTS**: Developing and refining measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment
3) **RESEARCH**: Improving understanding of physical processes important in intensity change for a TC at all stages of its life cycle

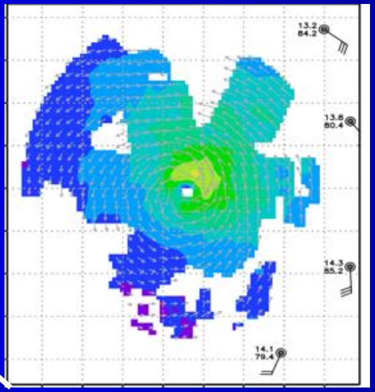


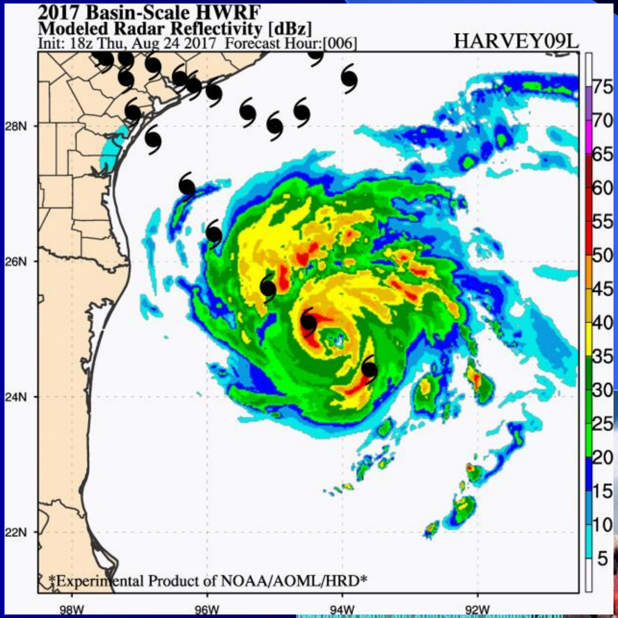
IFEX FORECASTS:
Assimilation of data into numerical models

#NOAAHurricaneAware

- NOAA P-3 transmitted Tail Doppler radar data in real-time for assimilation into HWRF



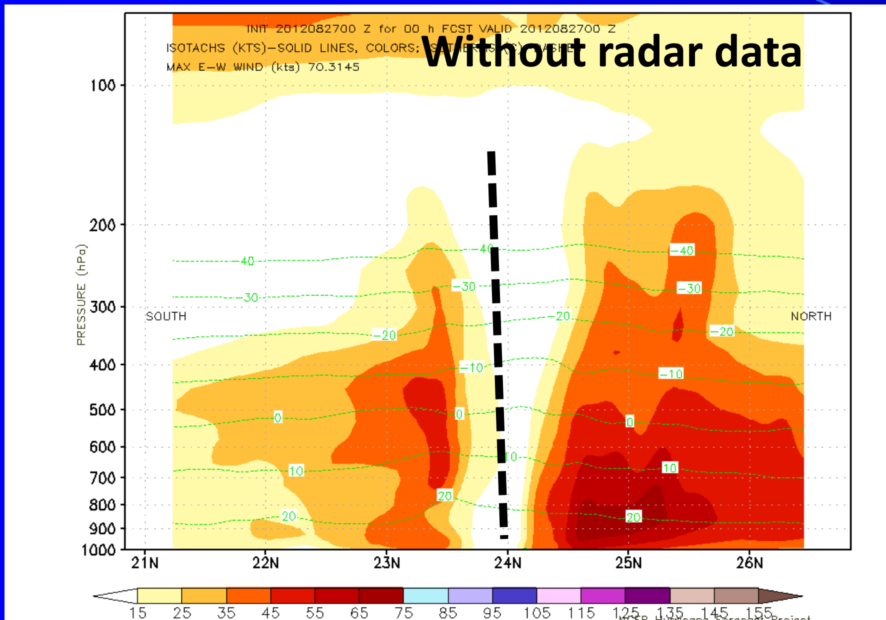


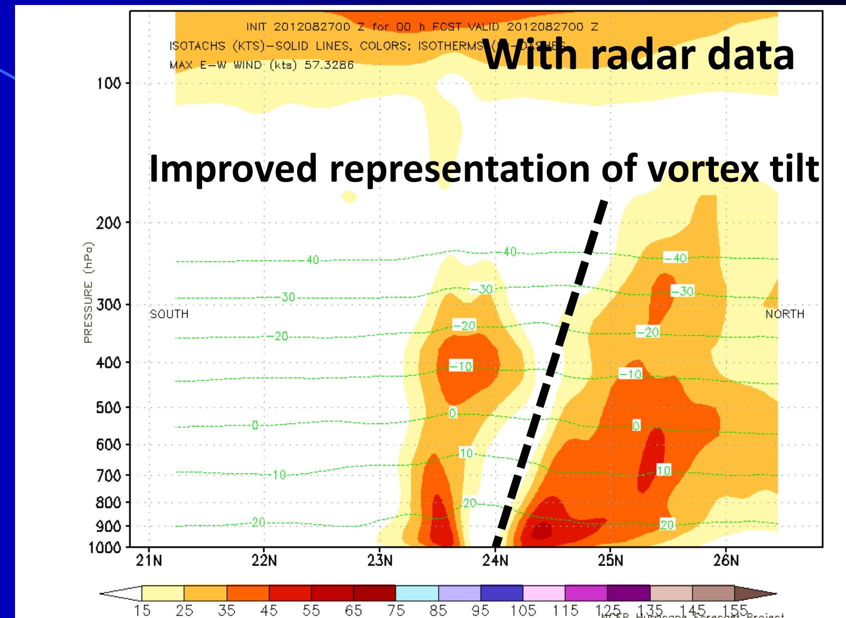


Hurricane Harvey (2017)

IFEX FORECASTS: Data assimilation

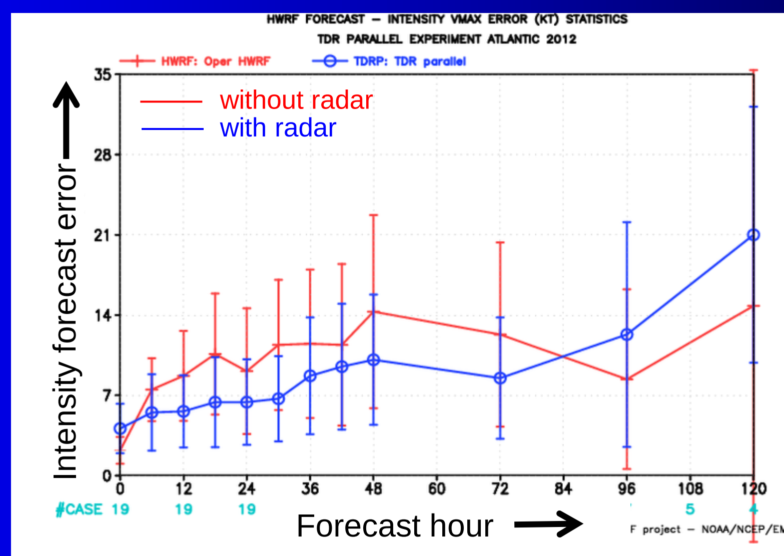
Vertical cross section of wind speed in Isaac (2012) at start of model forecast





Impact of assimilating inner-core observations into forecast model

- Use of airborne Doppler improved initial vortex structure
- Resulting intensity forecast was improved
- Many more cases must be evaluated, DA system must be improved (ongoing)

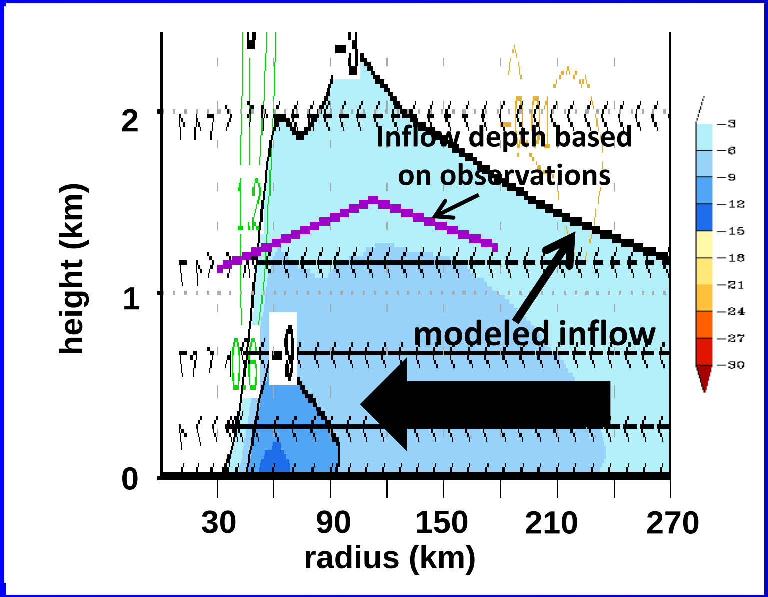


IFEX FORECASTS: Model evaluation

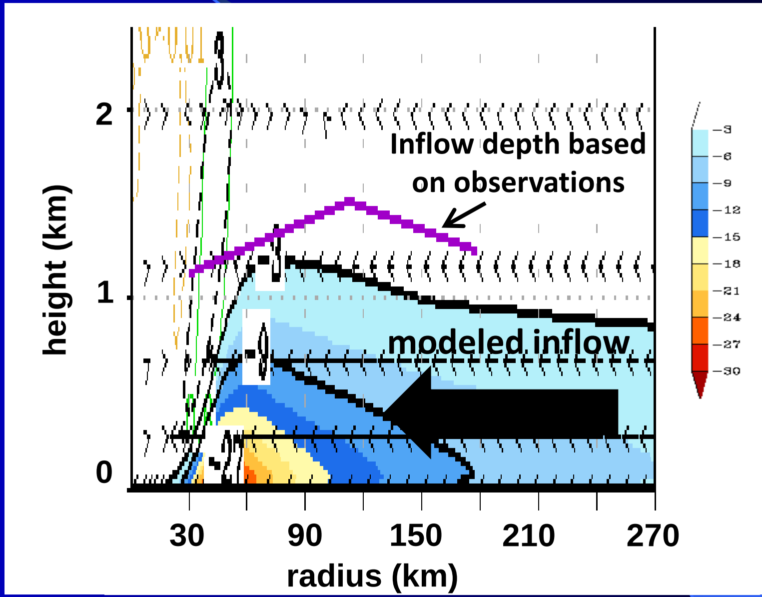
Sensitivity of radial wind to mixing processes in low levels

Radial inflow for different model runs

Old mixing version

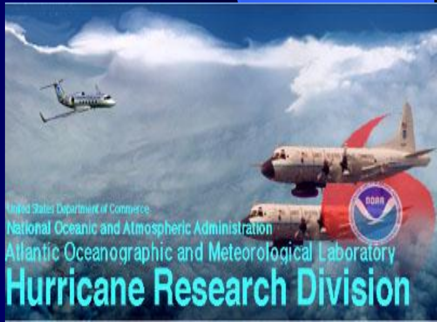


New mixing version based on observations



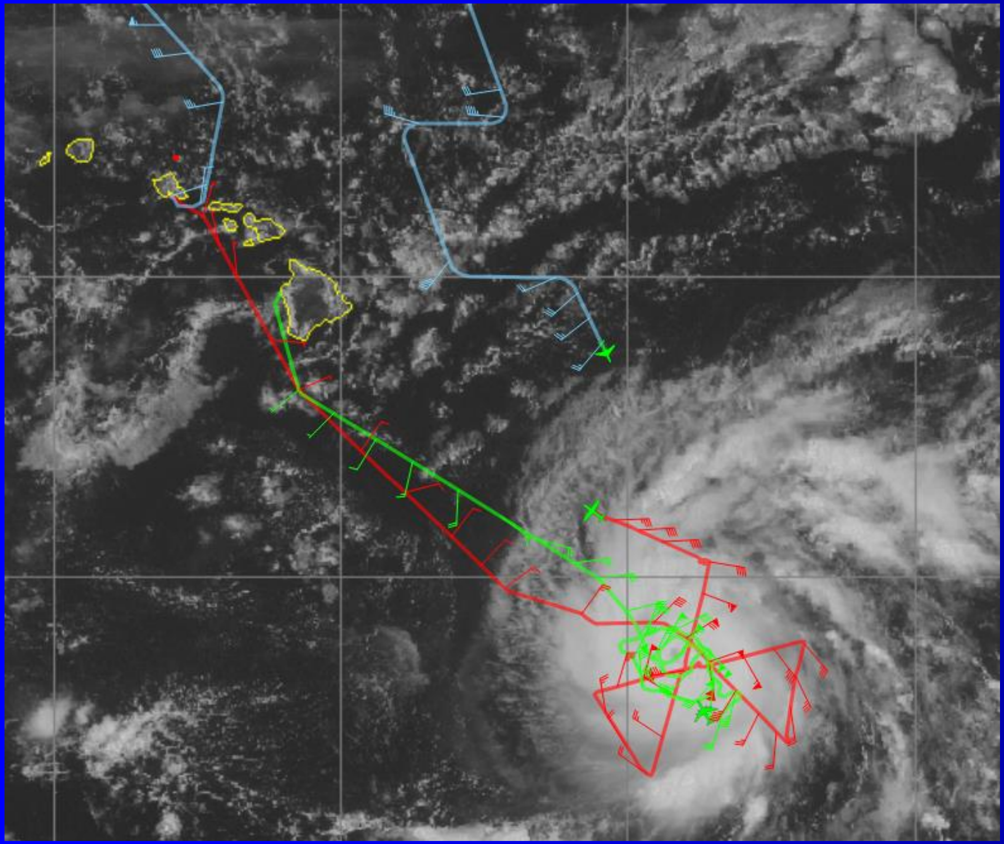
- **Inflow layer too deep**
- **Inflow strength too weak**

- peak radial inflow stronger with more accurate mixing
- depth of inflow layer more consistent with dropsonde composites using more accurate mixing



IFEX NOWCASTS:
Improved representation of TC structure

Hurricane Lane missions (19-23 August 2018)

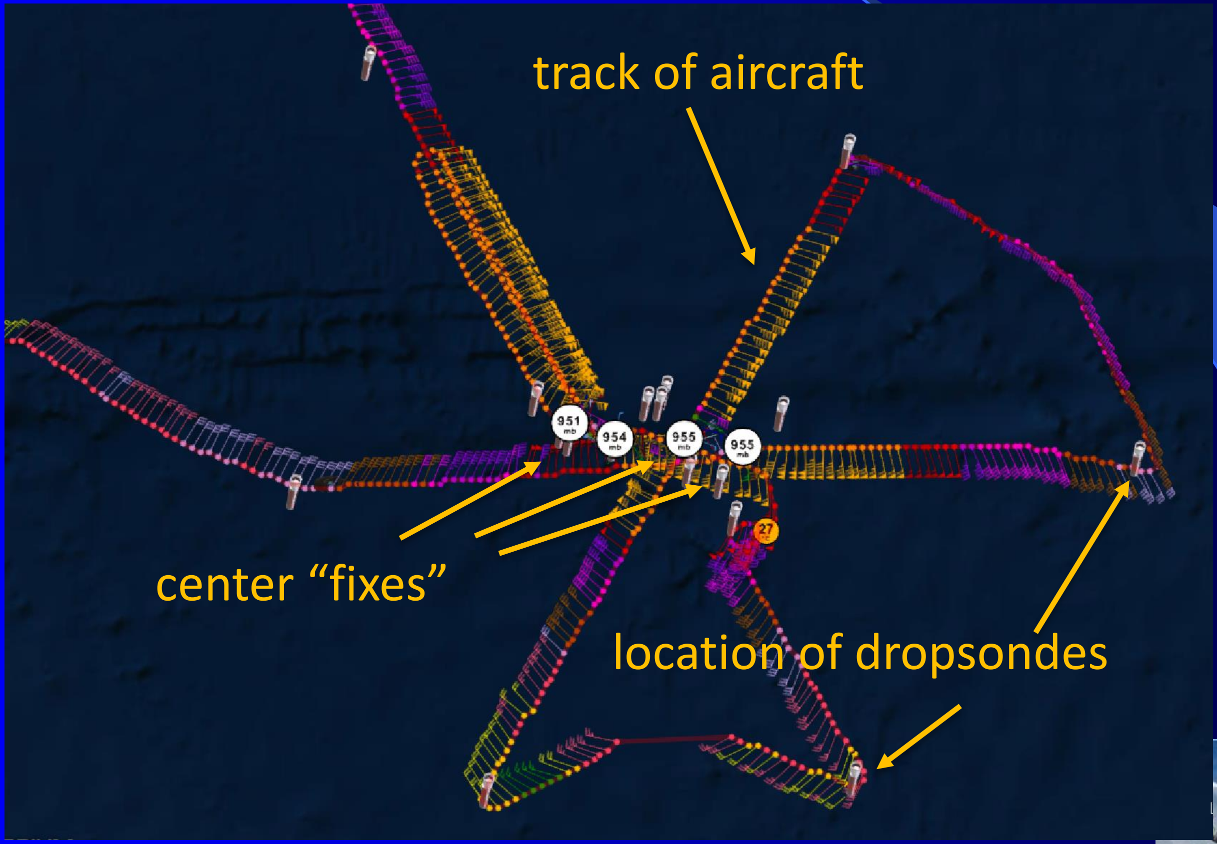


Provided by Heather Holbach

National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
Hurricane Research Division

IFEX NOWCASTS:
Improved representation of TC structure

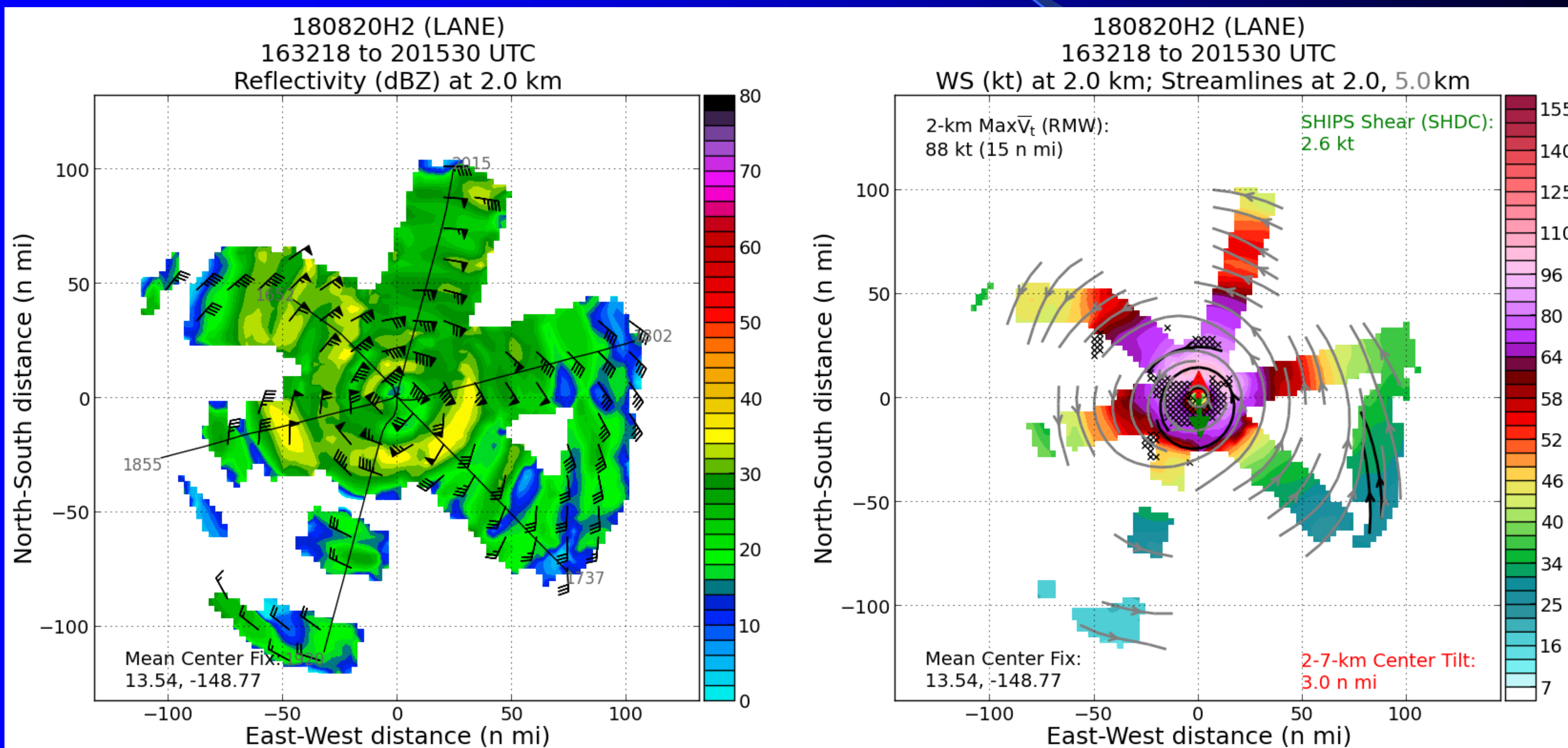
Real-time displays of flight-level winds and aircraft "fixes" for Lane



- Aircraft provide a detailed look at the inner-core structure of hurricanes, including winds, pressures, temperature, and moisture that satellites can not reliably measure
- Aircraft have limited range and endurance, unlike satellites

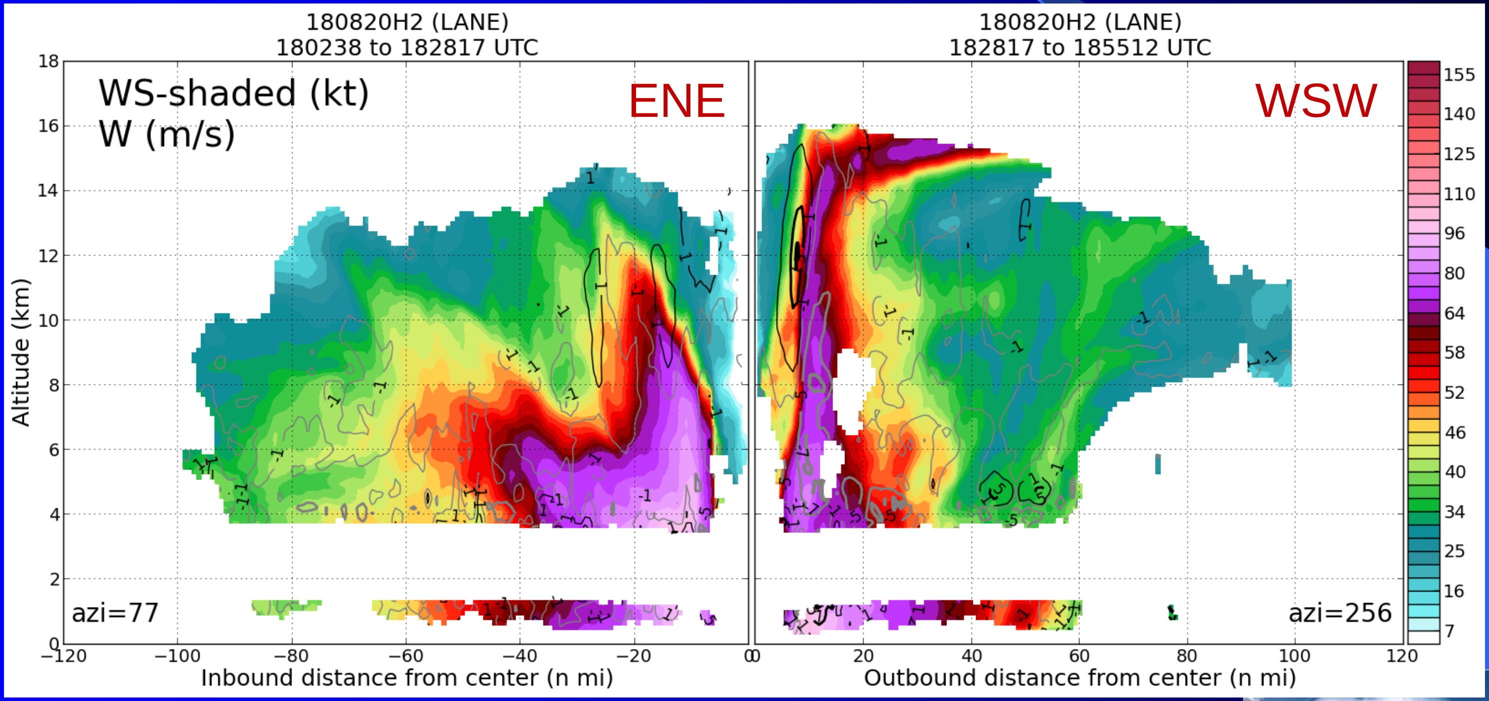
IFEX NOWCASTS:
Improved representation of TC structure

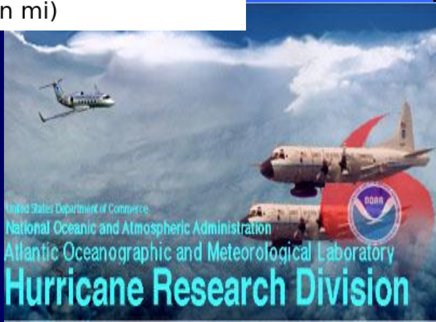
Real-time display of reflectivity and winds in Hurricane Lane



IFEX NOWCASTS:
Improved representation of TC structure

Real-time vertical cross section of wind speeds in Hurricane Lane

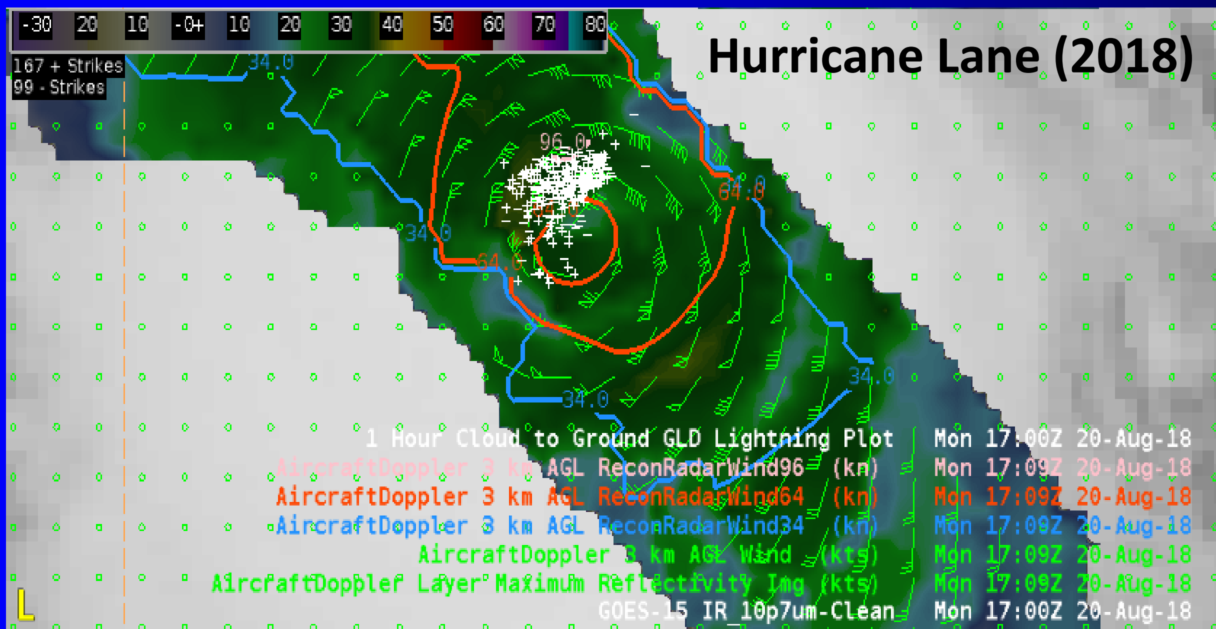




IFEX NOWCASTS:
Improved representation of TC structure

Integration of satellite, airborne observations in real time

Reflectivity, wind speeds at 3 km from aircraft
Lightning flashes from GOES GLM



Courtesy Stephanie Stevenson, NHC

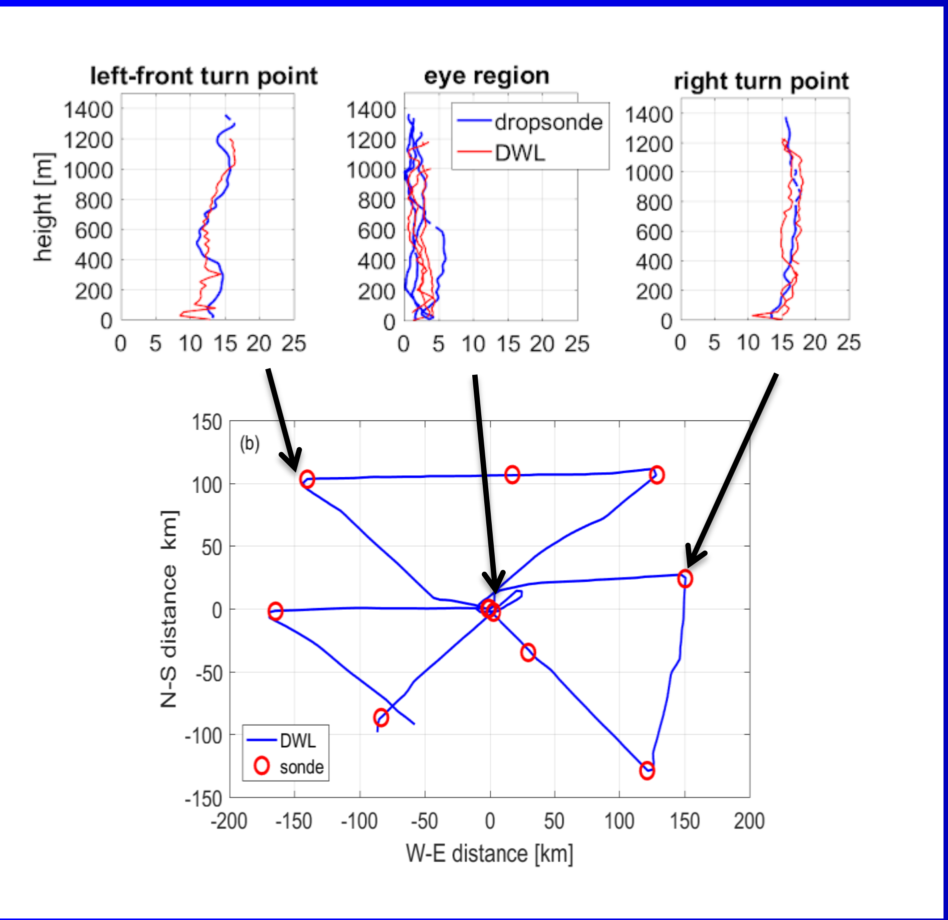
- Satellite showed lightning, indicator of deep convection
- Lightning located inside the radius of maximum wind
- Indicator of intensification

IFEX NOWCASTS:

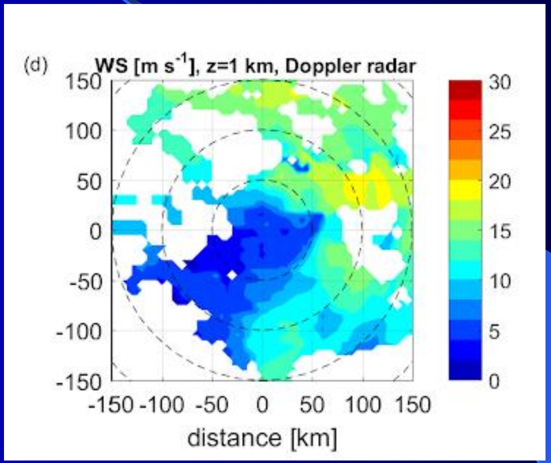
Improved representation of TC structure

Doppler Wind Lidar

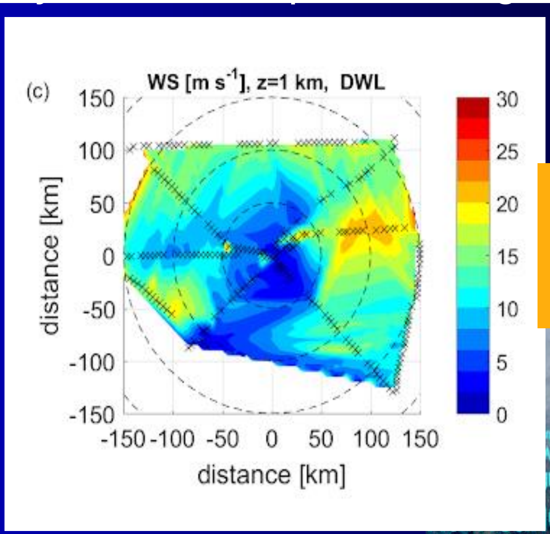
Drop locations and comparisons with sondes for TS Erika (2015)



Analysis of wind speeds using airborne Doppler



Analysis of wind speeds using DWL



- DWL can “fill in gaps” from radar

IFEX RESEARCH: Improve understanding

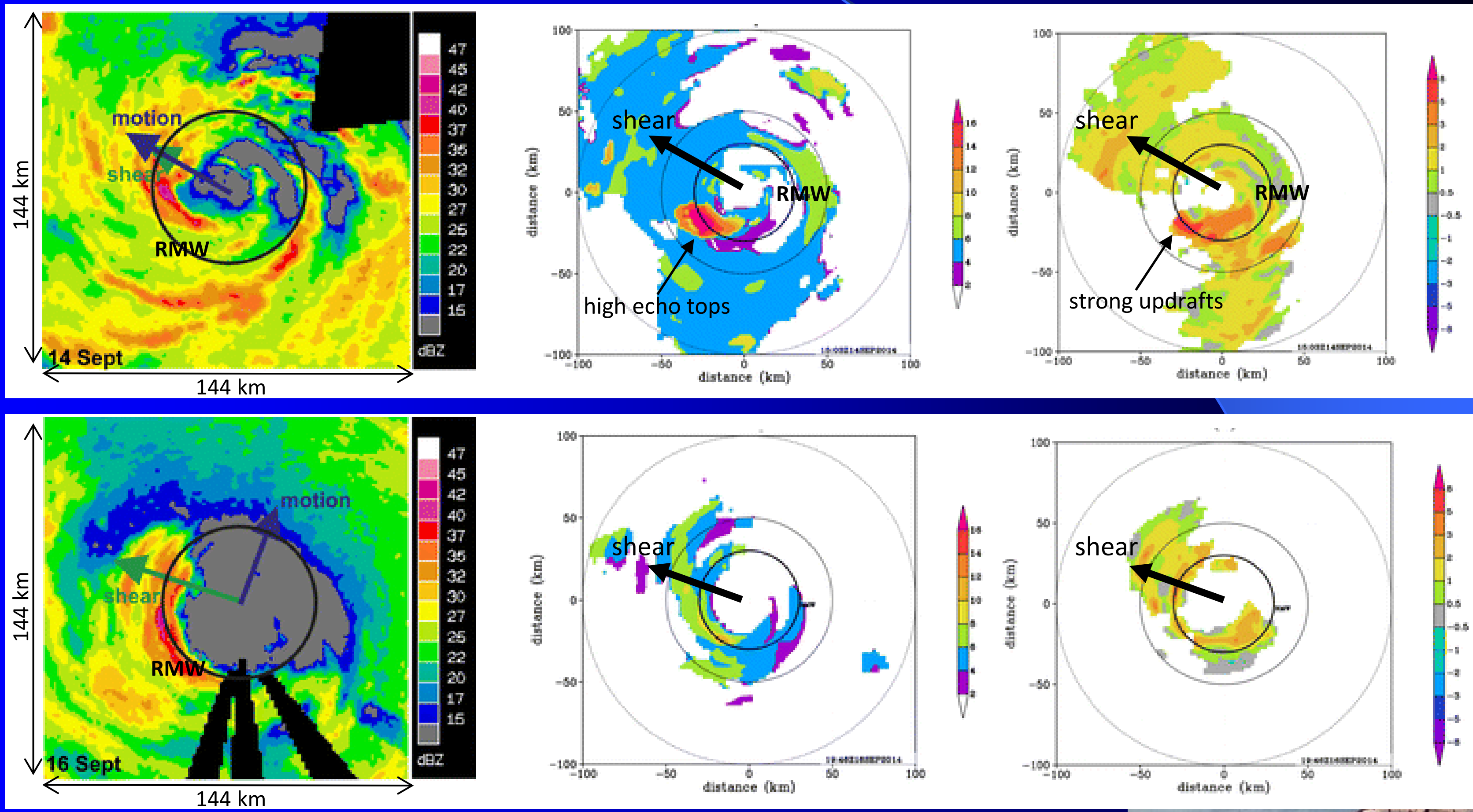
Vortex intensification in shear

Reflectivity, echo tops, and upper-level updrafts in Hurricane Edouard (2014)

Lower fuselage reflectivity (shaded, dBZ) | 20 dBZ echo top heights from airborne Doppler (shaded, km) | Peak updrafts in 8-16 km layer from airborne Doppler (shaded, m/s)

14 Sept - RI

16 Sept - SS

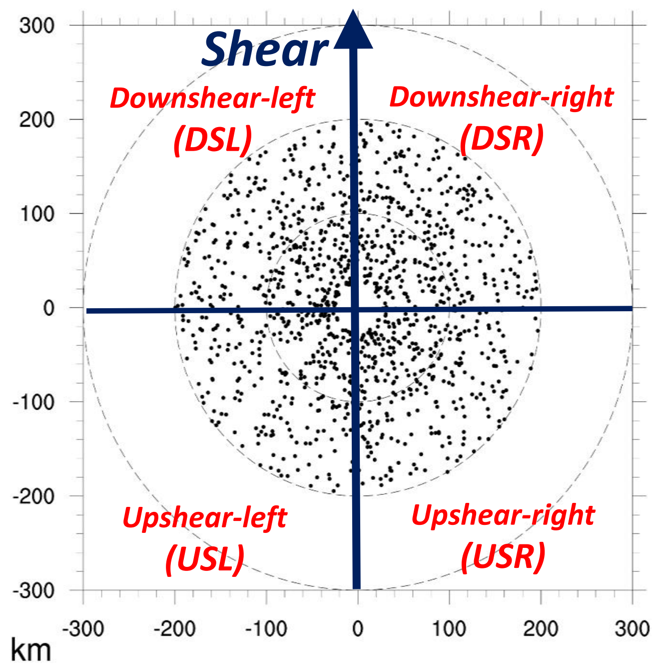


- 14 Sept (RI period): Strong updrafts, high echo tops upshear left and inside RMW
- 16 Sept (SS period): Weaker updrafts, mostly downshear left, at RMW
- Can we predict likelihood of persistence of convection upshear based on obs, model?

IFEX RESEARCH: Improve understanding
Shear-relative variation in low-level stability and RI

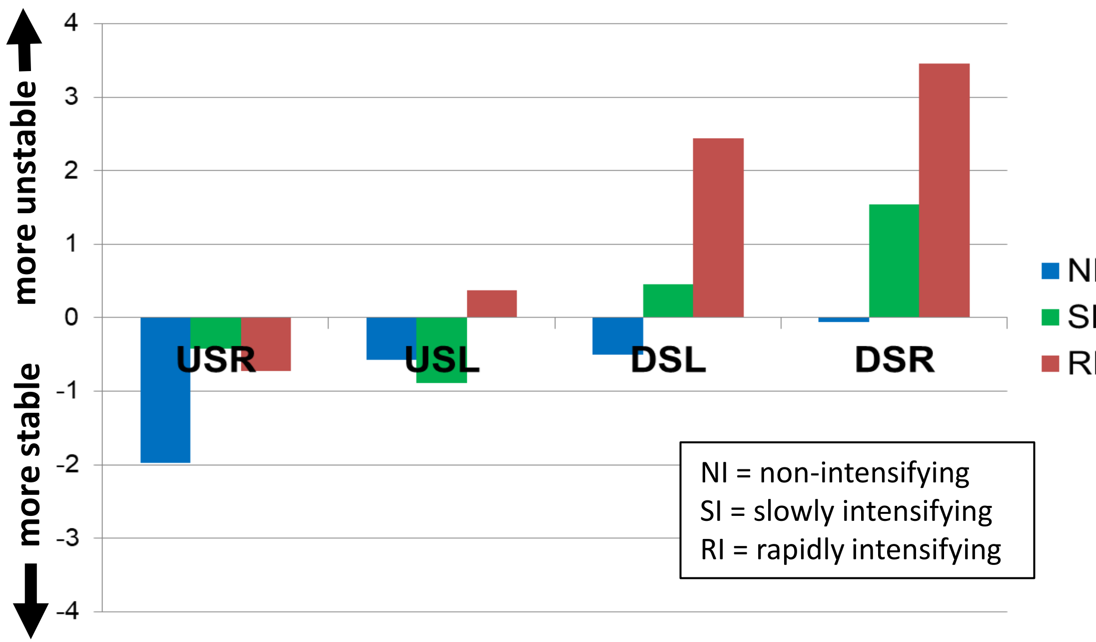
Is there a difference in the low-level stability for RI storms?

Locations of dropsondes used in composite



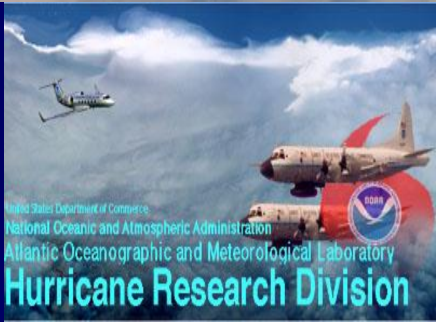
~1200 sondes used

Low level stability in different quadrants

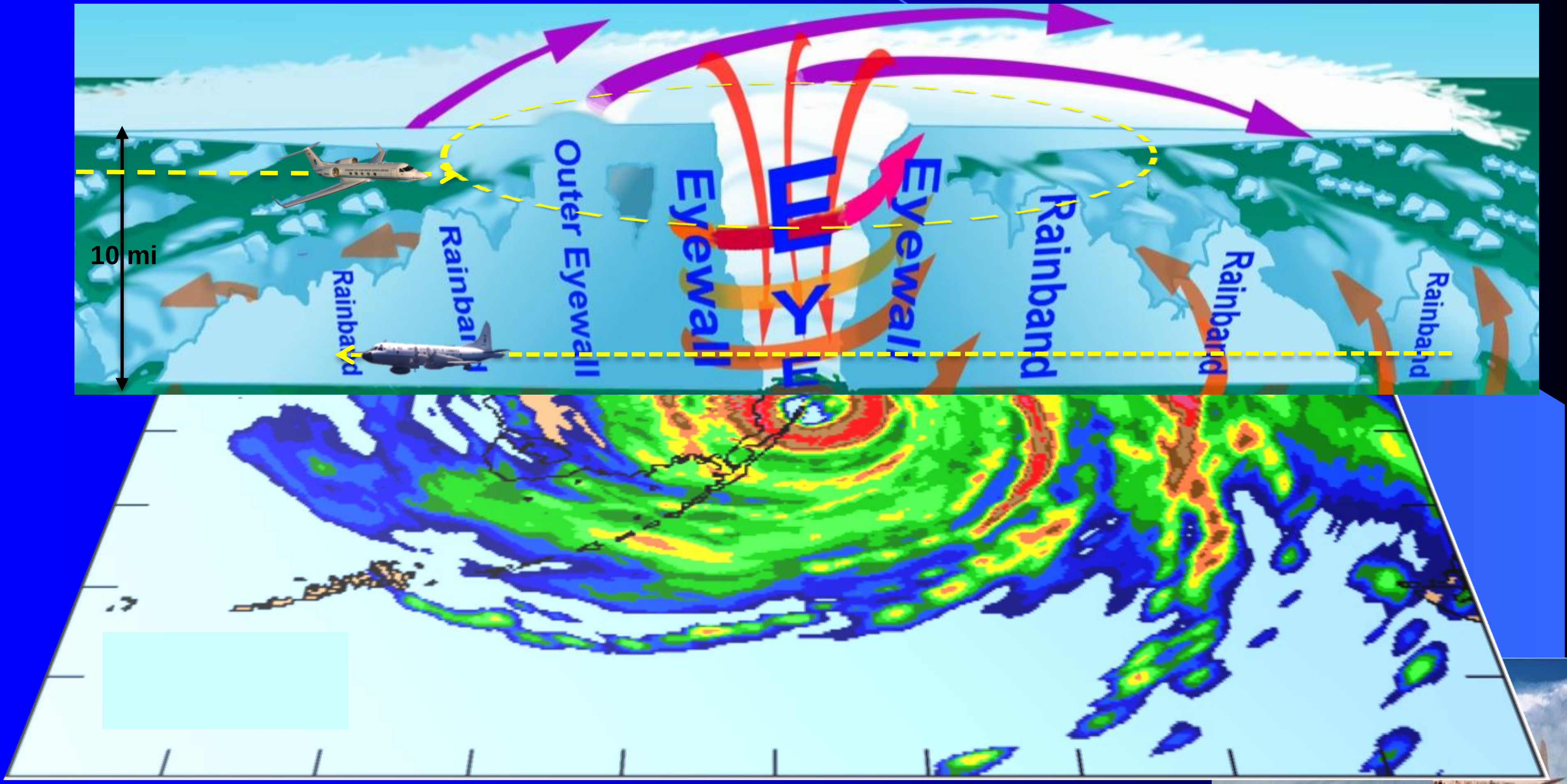


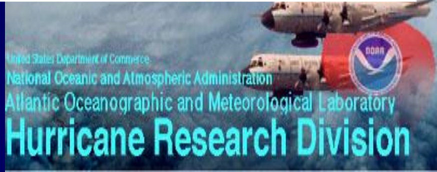
- Rapidly-intensifying storms have more unstable low levels all around the storm, especially DSR, DSL
- Non-intensifying storms are stable in all quadrants

3. Flight profiles



Aircraft sampling of TCs

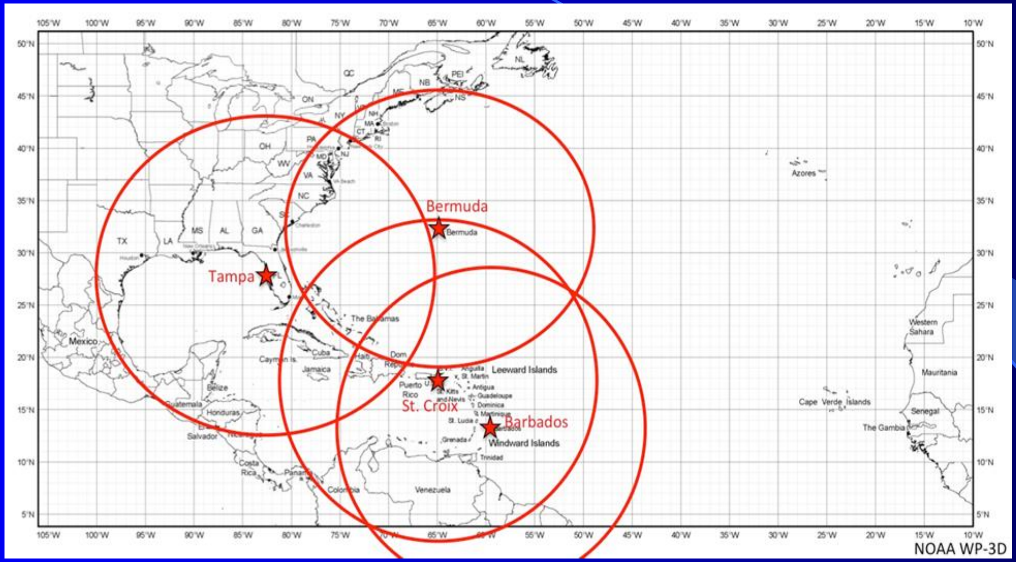




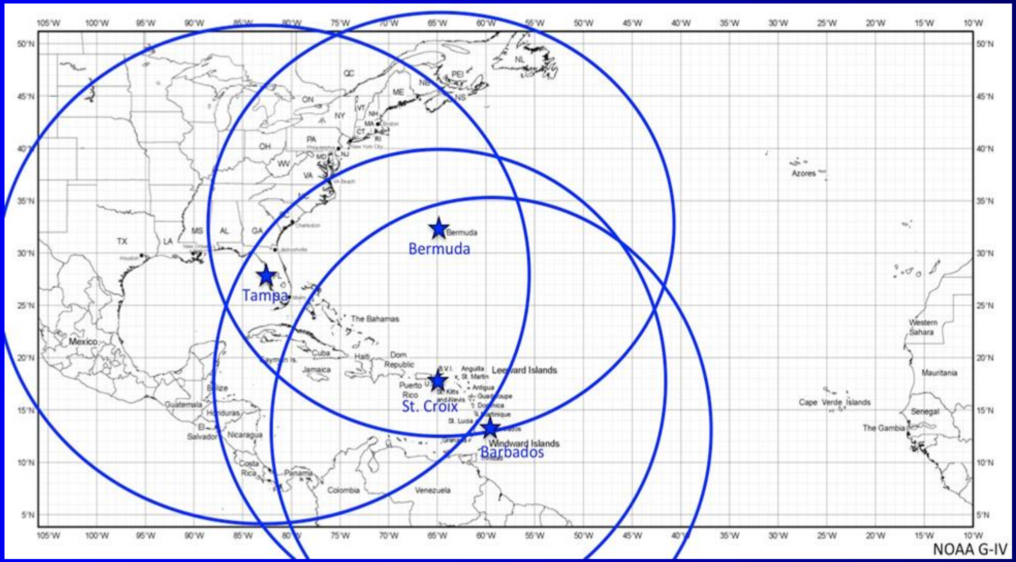
P-3 and G-IV Atlantic bases of operations

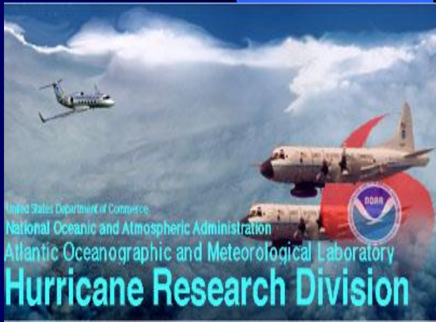
Assuming 2 hours of on-station time

P-3



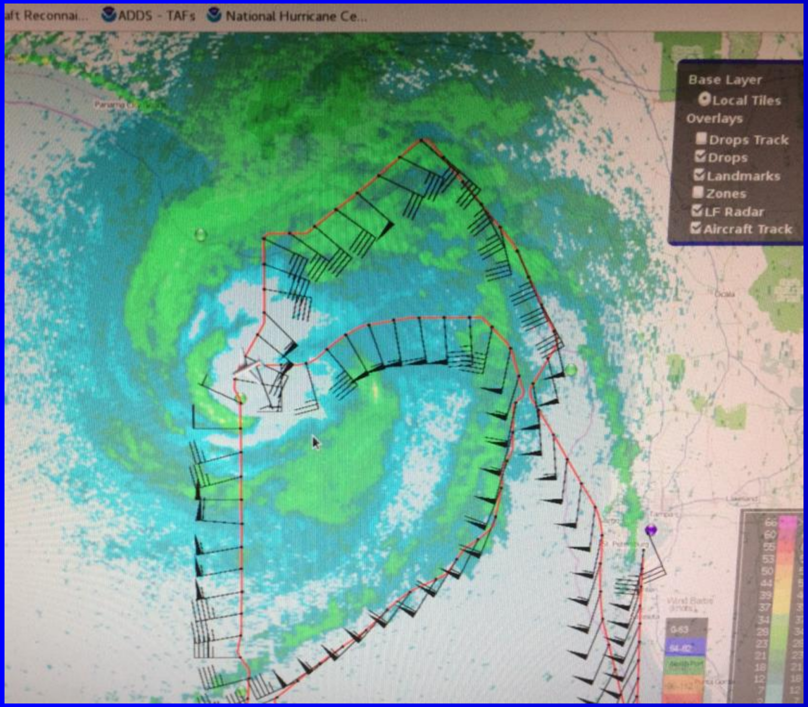
G-IV



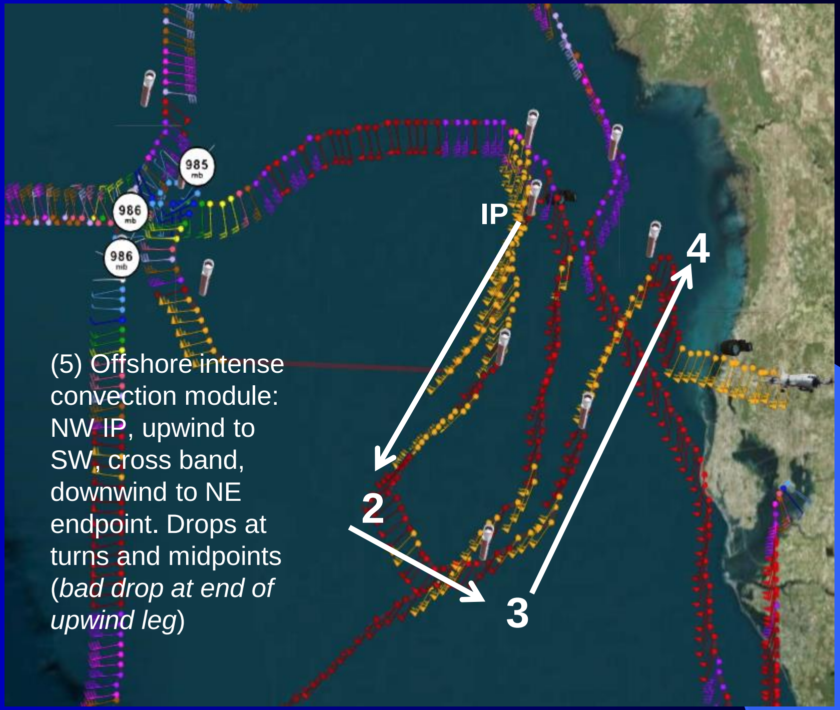


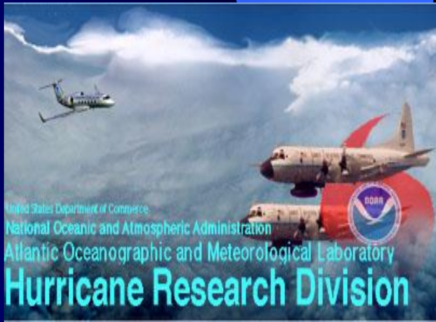
Sample P-3 Flight track into Hurricane Hermine September 1, 2016

Lower fuselage reflectivity (shaded, dBZ) and flight-level winds (kt)



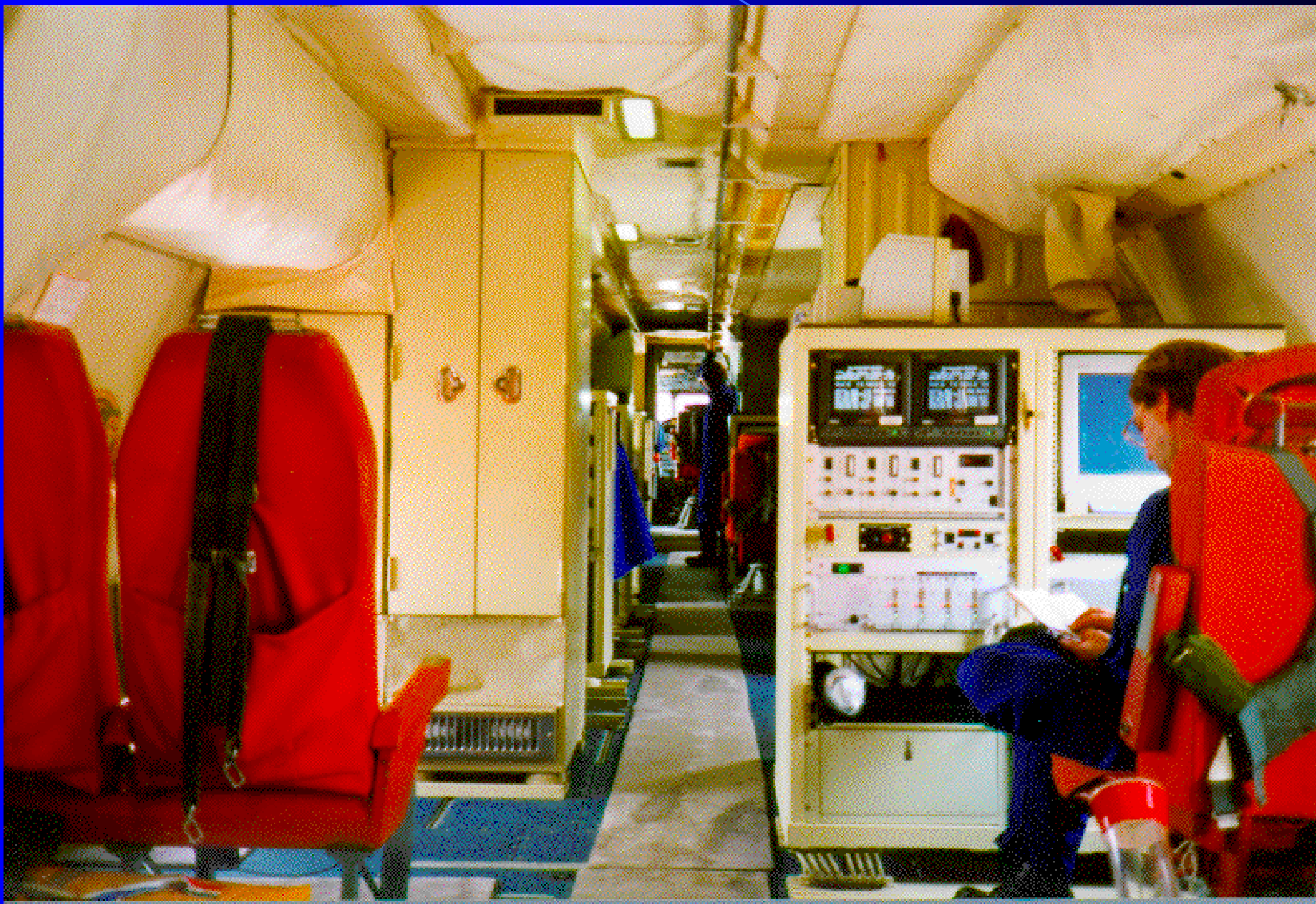
Flight track and flight-level winds (kt)





4. Views from the aircraft

Inside the P-3 Aircraft



Dropsonde release on P-3

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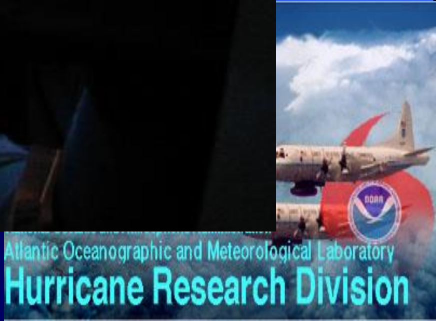
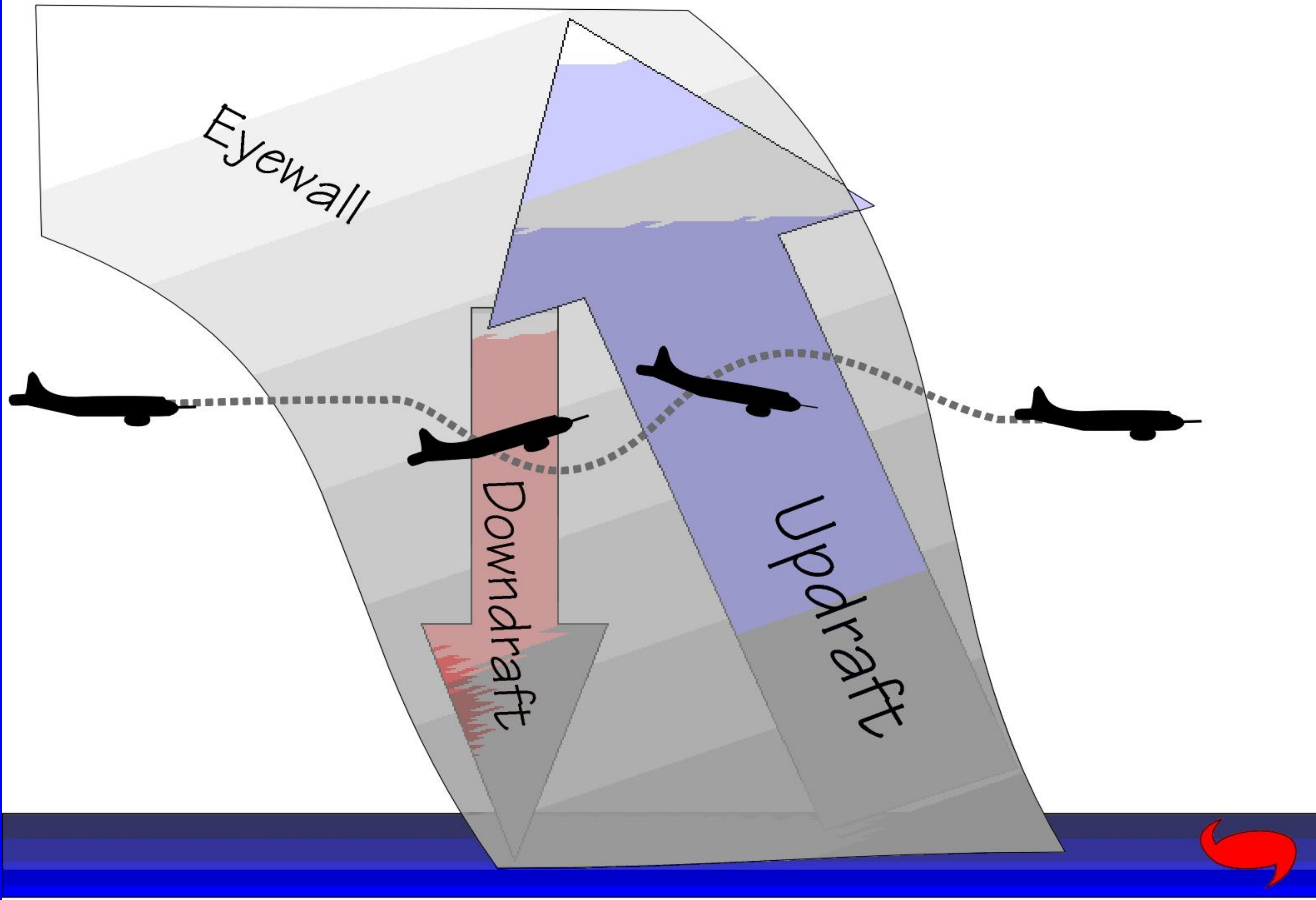
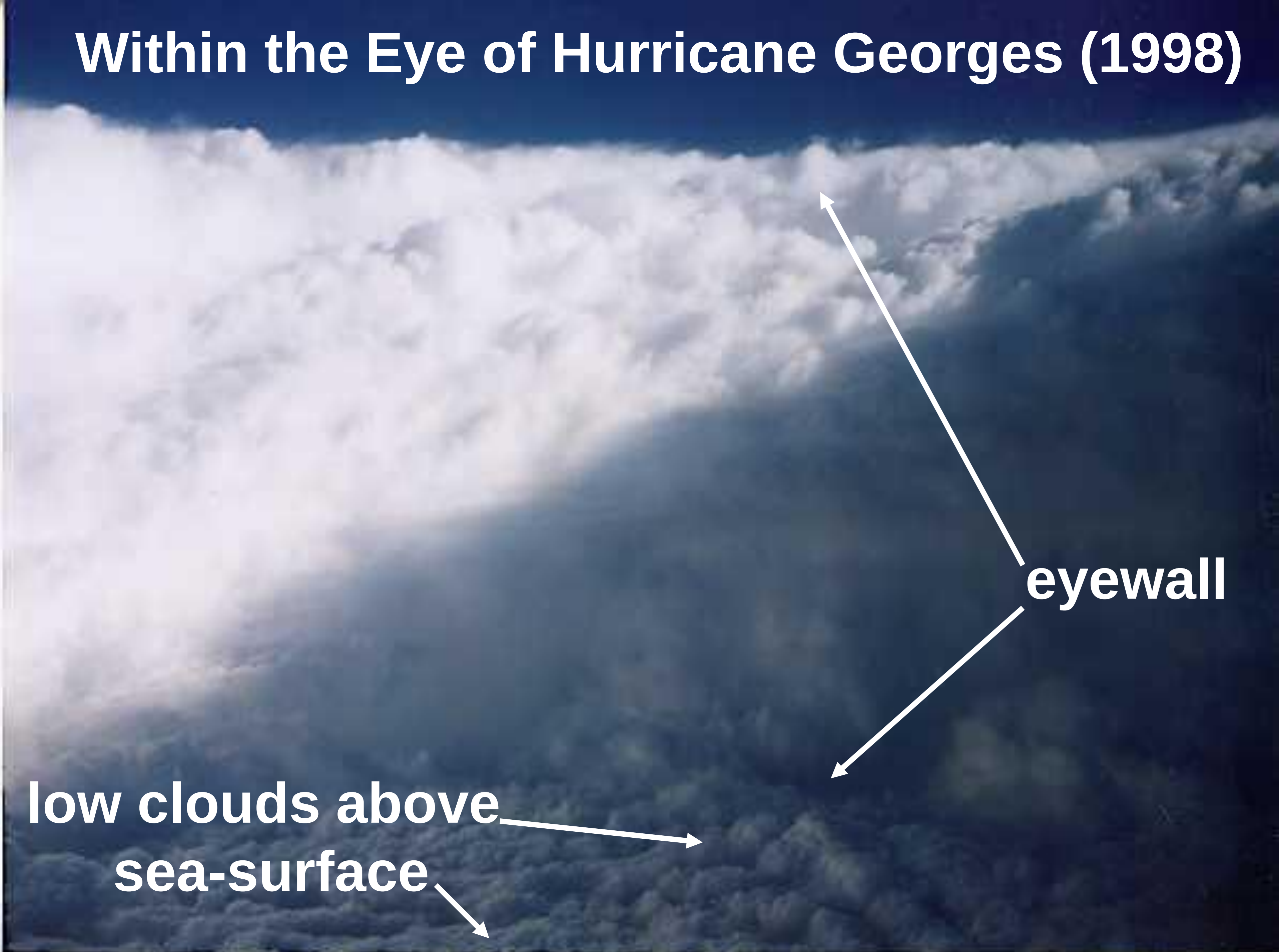
Inside the G-IV Aircraft



Hurricane Eye Penetration

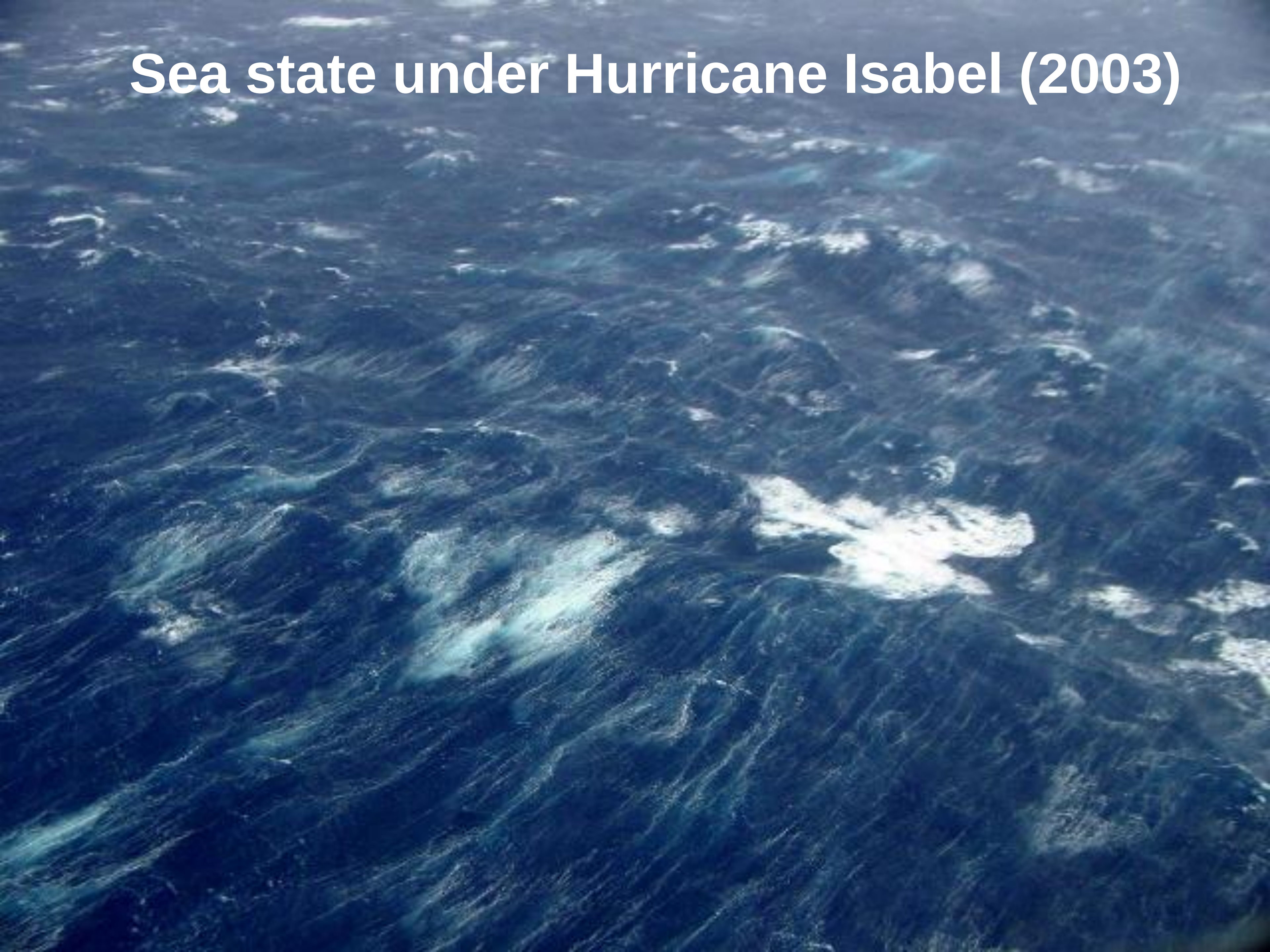


Within the Eye of Hurricane Georges (1998)




In the Eye of the Hurricane Isabel (2003)

Sea state under Hurricane Isabel (2003)



Low-level flight

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Stadium effect

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Impressed scientists

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Thank you!