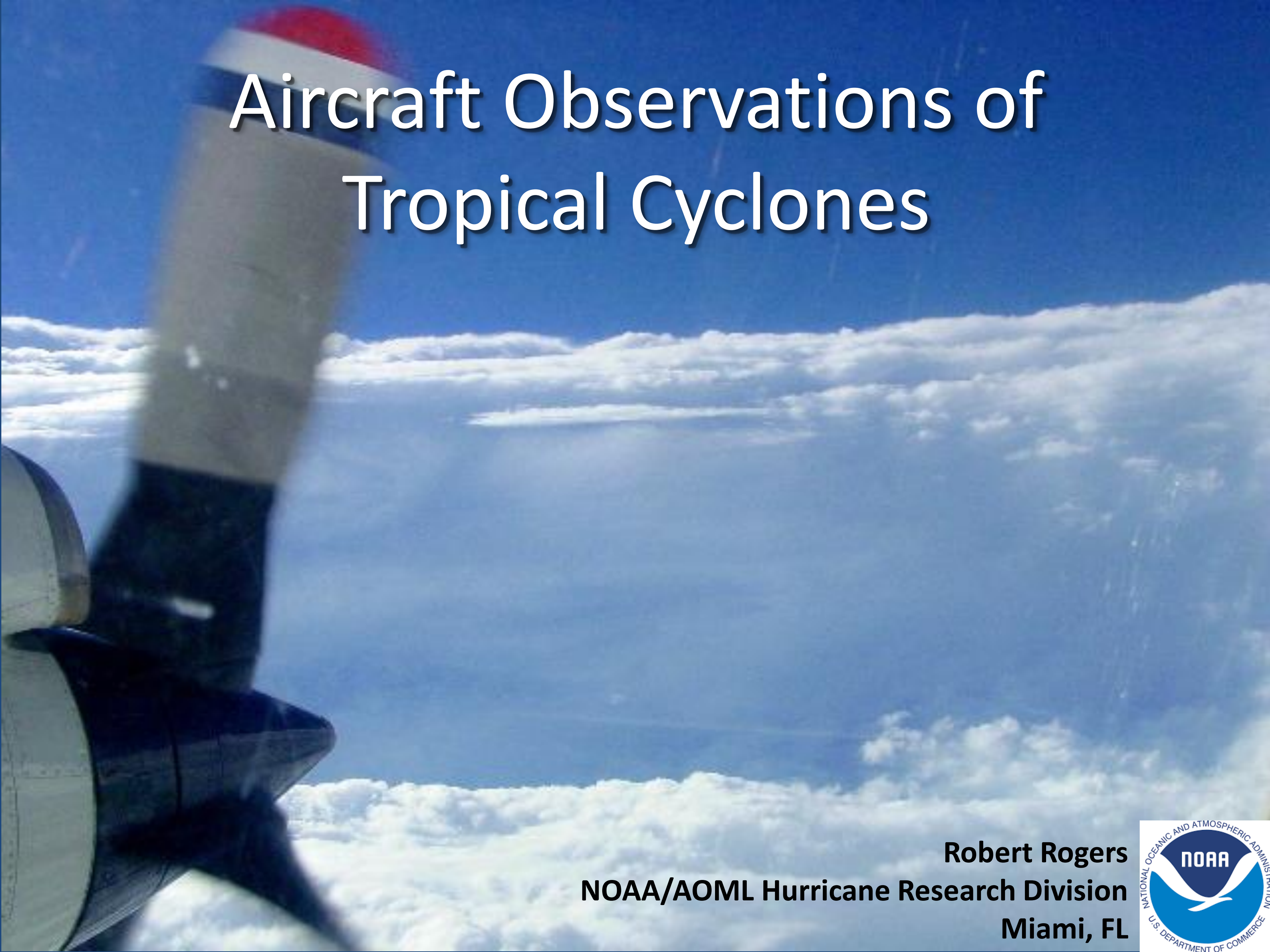
Aircraft Observations of Tropical Cyclones



Robert Rogers
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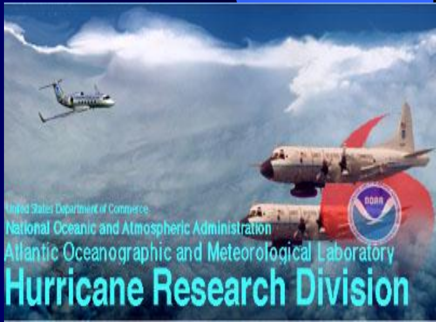
Motivation

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 –

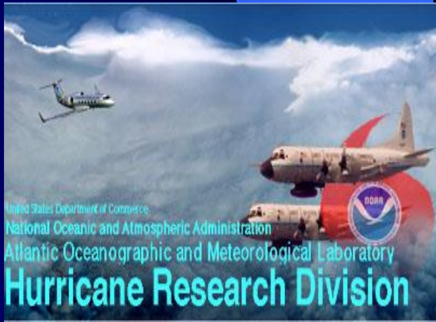
  airborne, spaceborne, and land-based

  -- 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

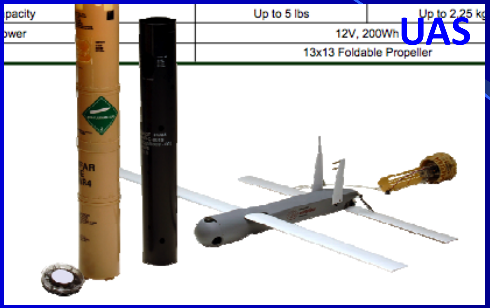


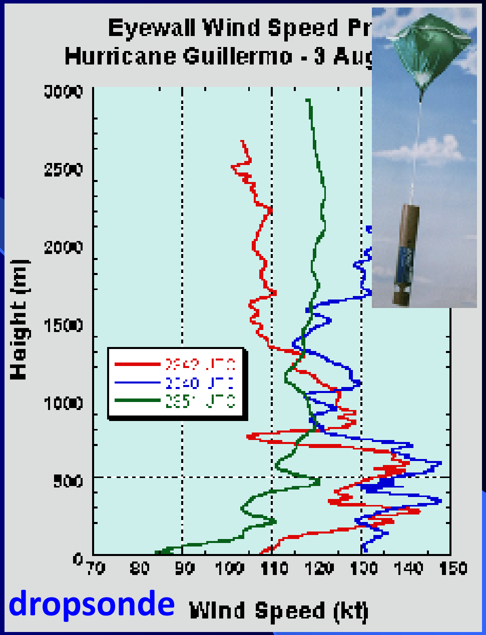
1. Tools for observing hurricanes

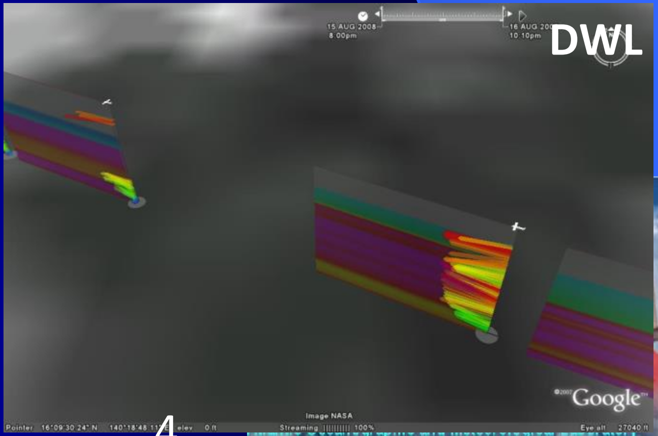
- **In-situ**
  - Wind, press., temp.

- **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)







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Tools for observing hurricanes

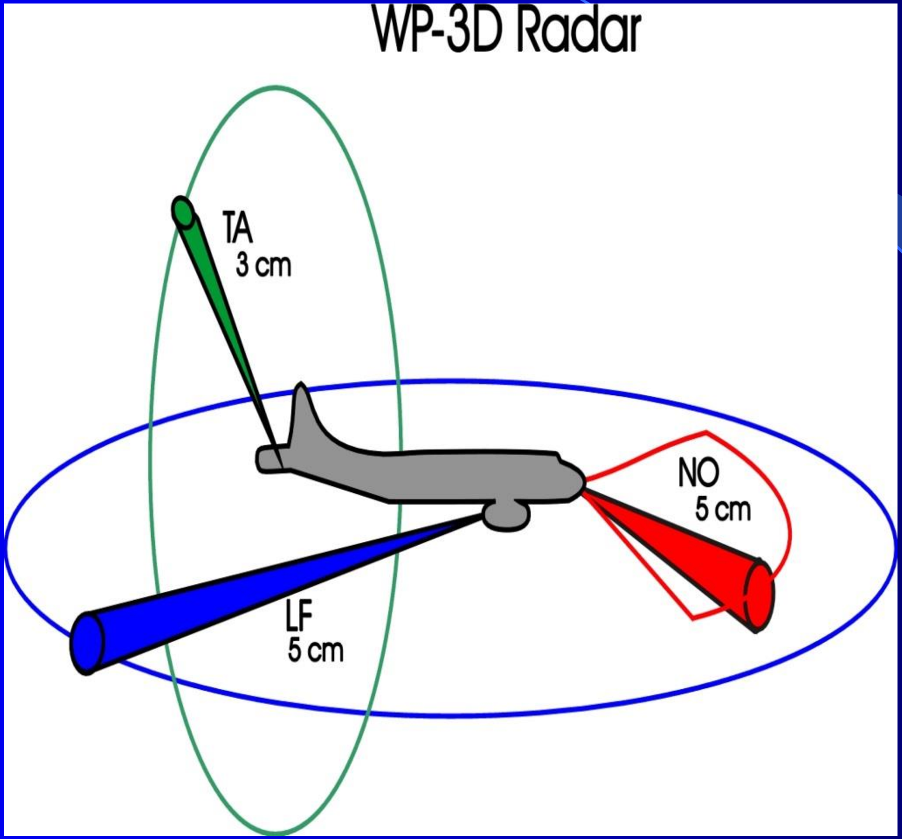
"Miss Piggy" Built in 1976 at Lockheed-Martin, Marietta, Georgia

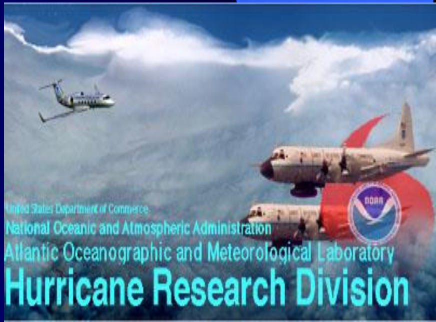
"Kermit" Built in 1975 at Lockheed-Martin, Marietta, Georgia

"Gonzo" Built in 1994 at Gulfstream Aerospace Corporation in Savannah Georgia

Airborne radar

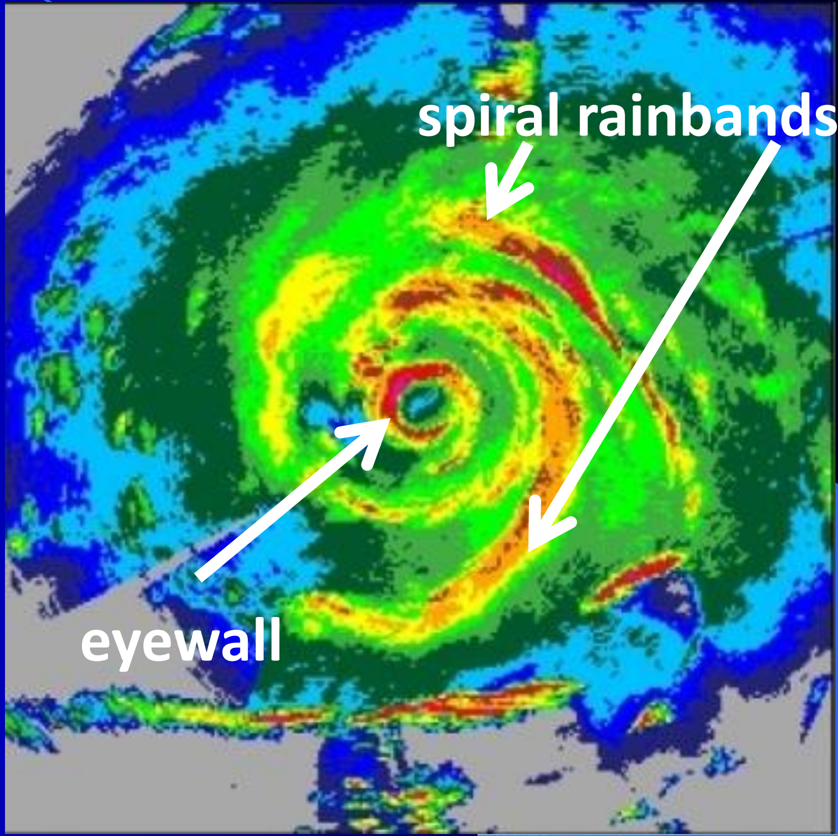
Radars on WP-3D

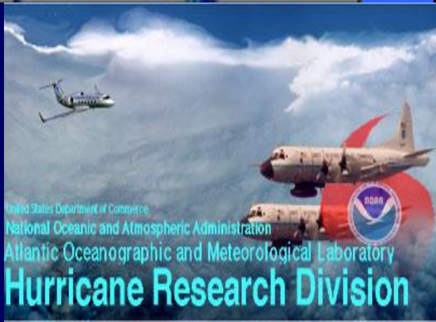




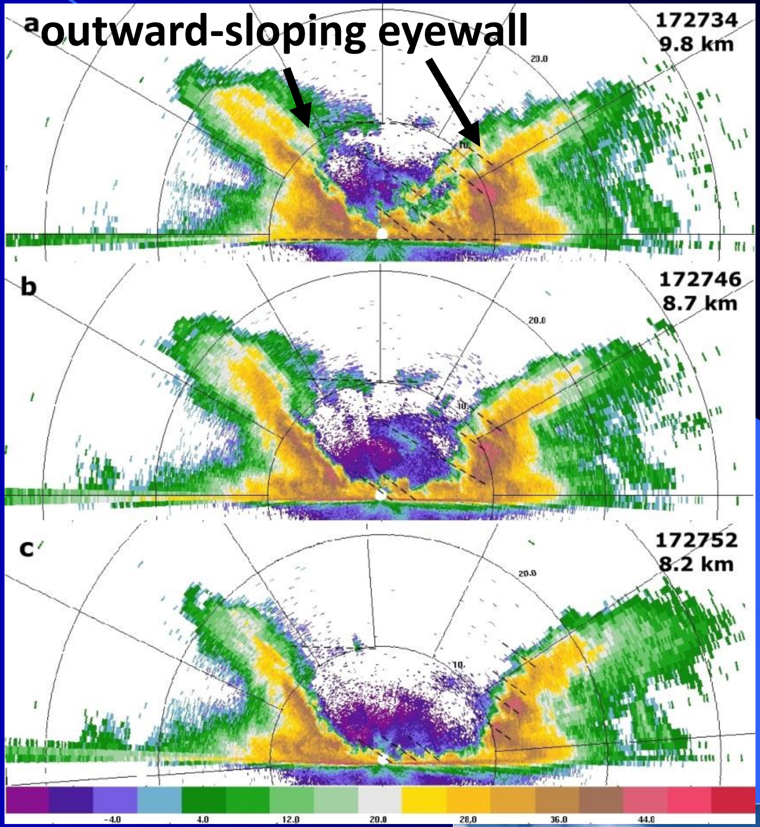
Lower Fuselage (LF) Radar

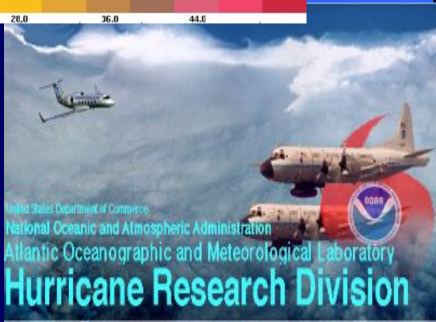
LF image of Hurricane Ivan (2004)



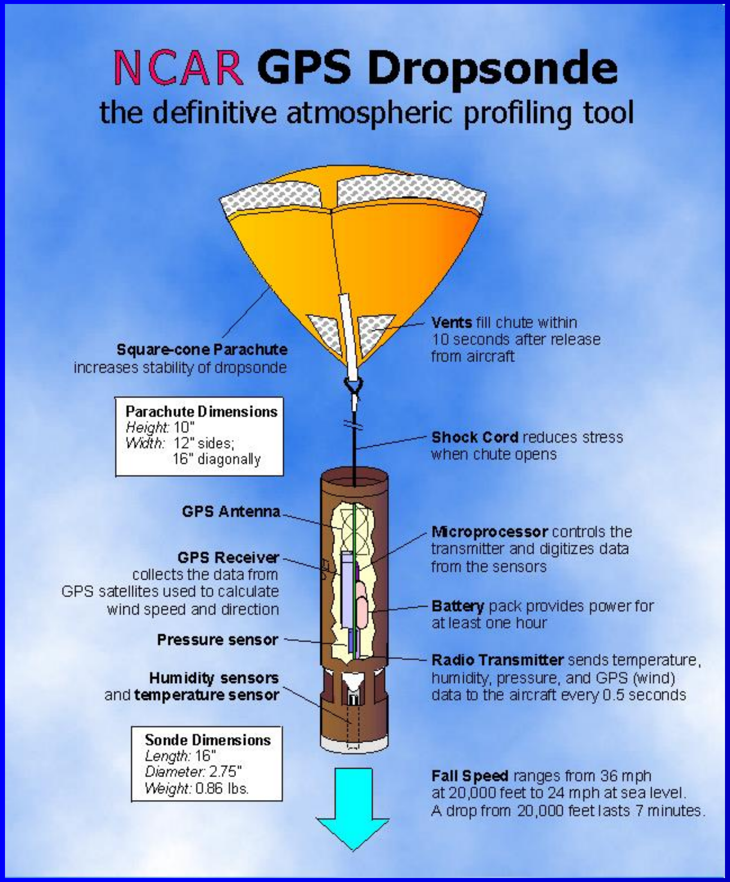


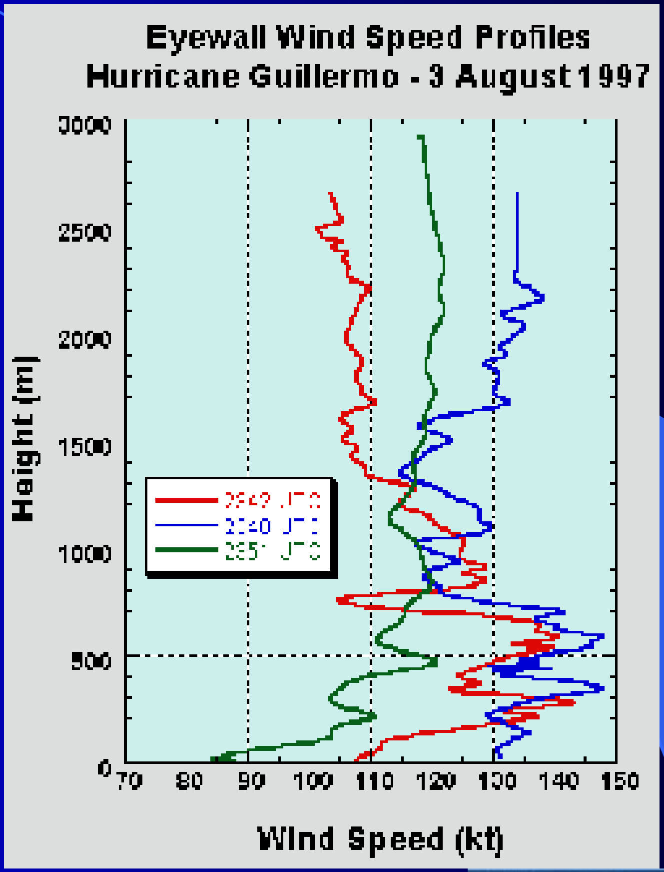
Tail Doppler Radar

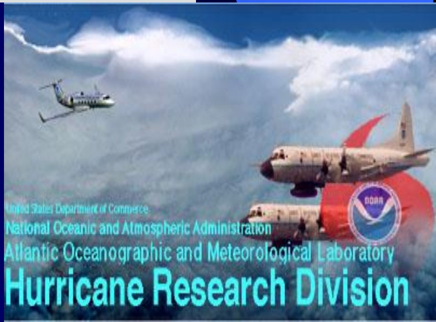




GPS dropsonde



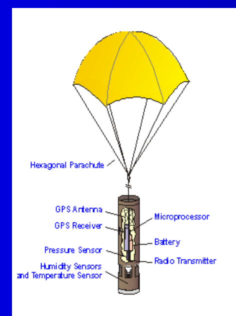




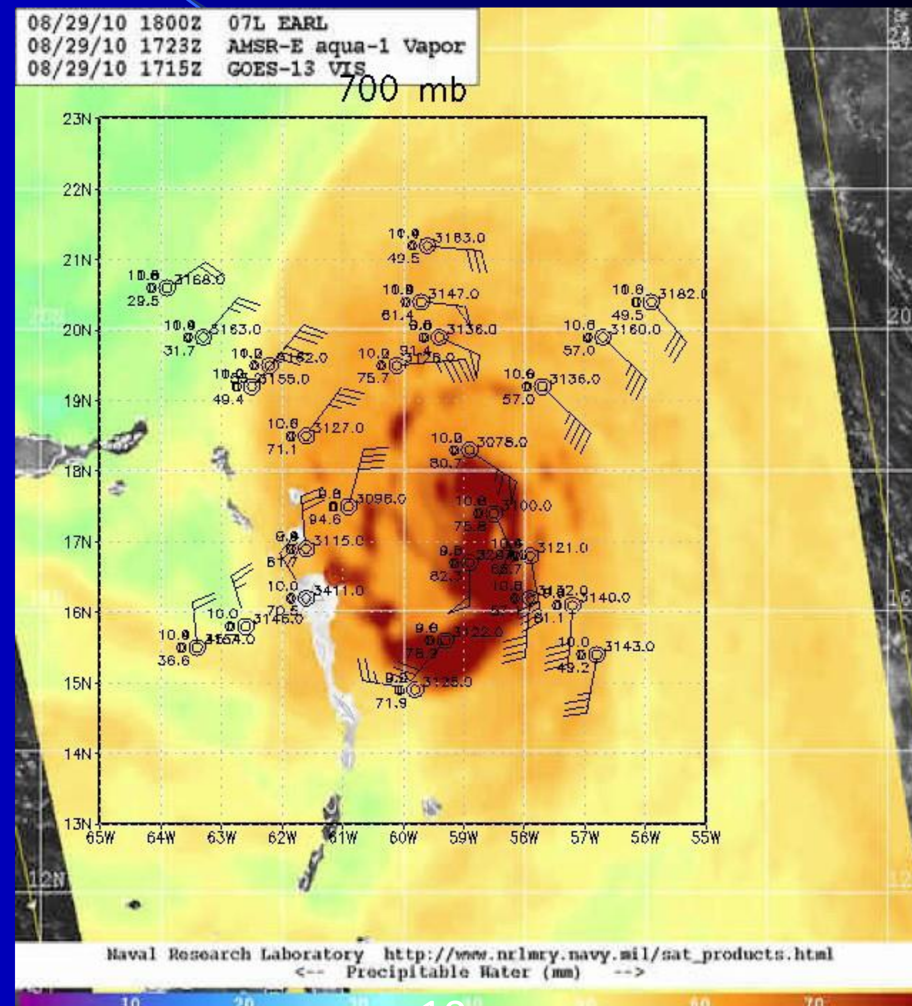
Scales sampled by Airborne Observations

Environmental structure

- Synoptic-surveillance using dropsondes



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



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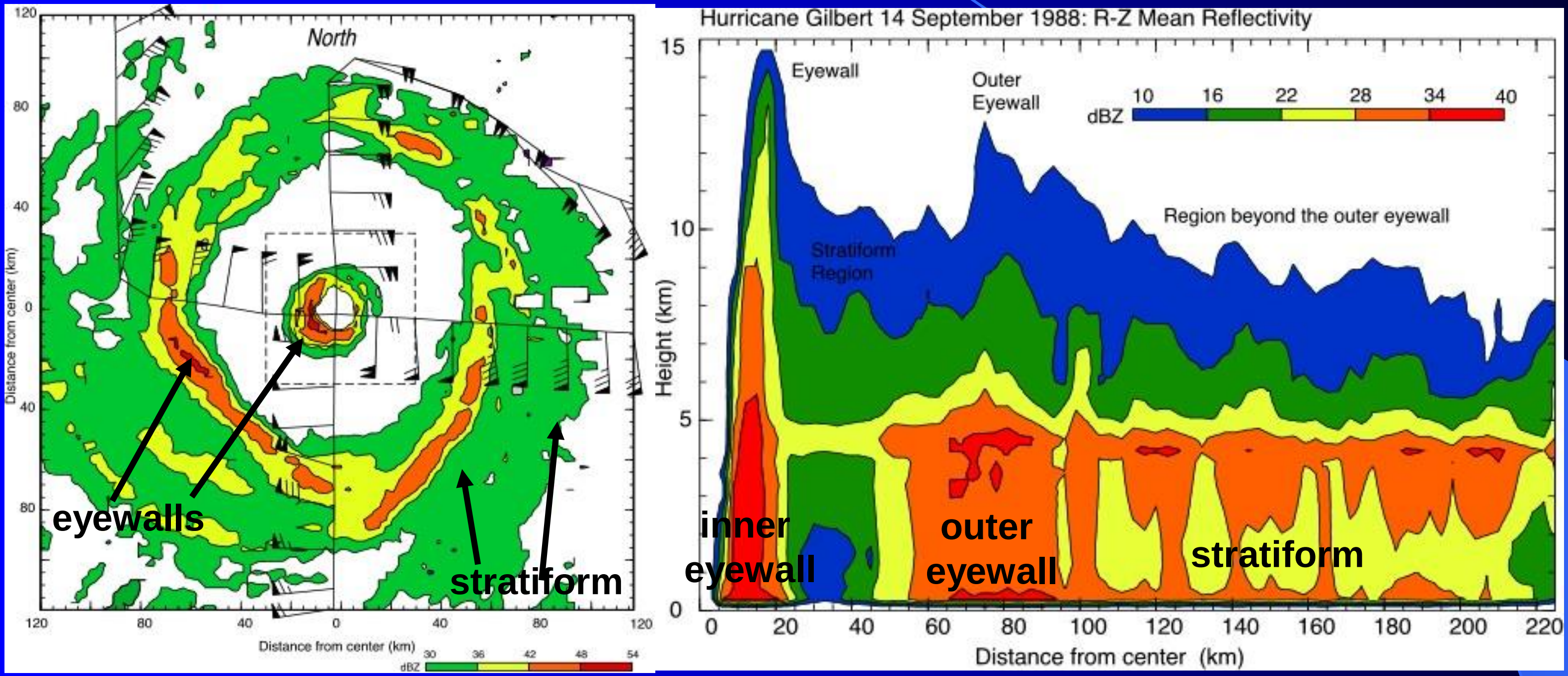
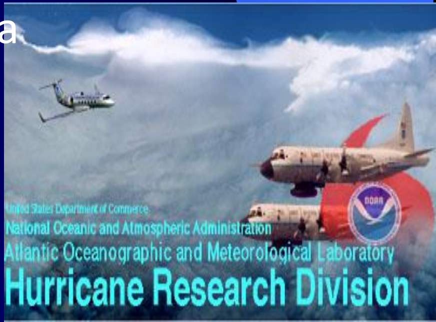
Scales sampled by Airborne Observations

Vortex Structure

Double eyewalls seen from airborne radar



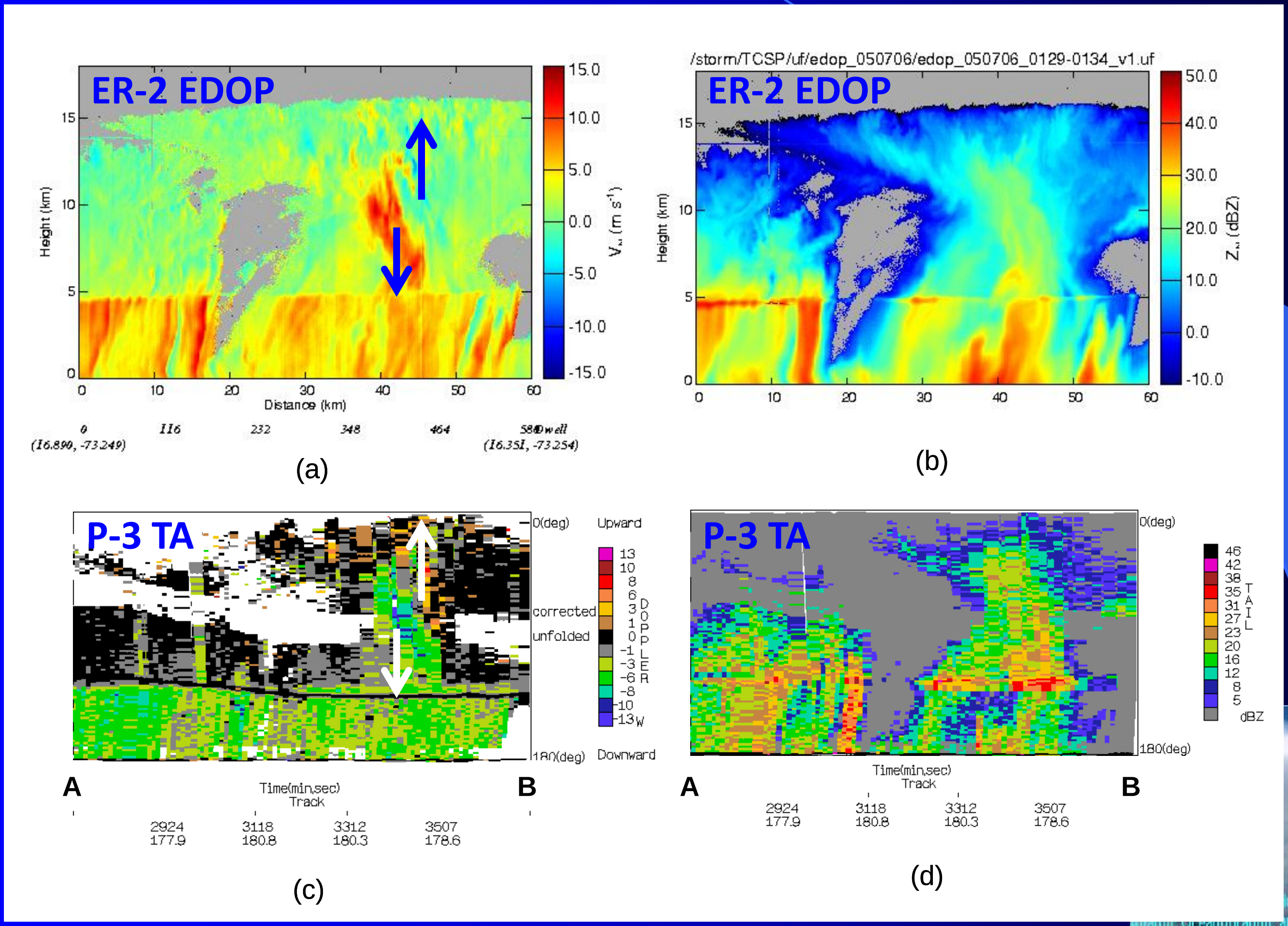
- Highest rain rates normally in eyewall, mostly convective, cover small area
- Lighter rain rates in stratiform areas outside eyewall, cover larger area



Scales sampled by Airborne Observations

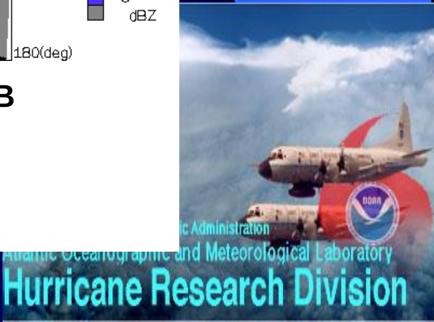
Convective Structure

Strong convection seen from radar



Vertical velocity (m/s)

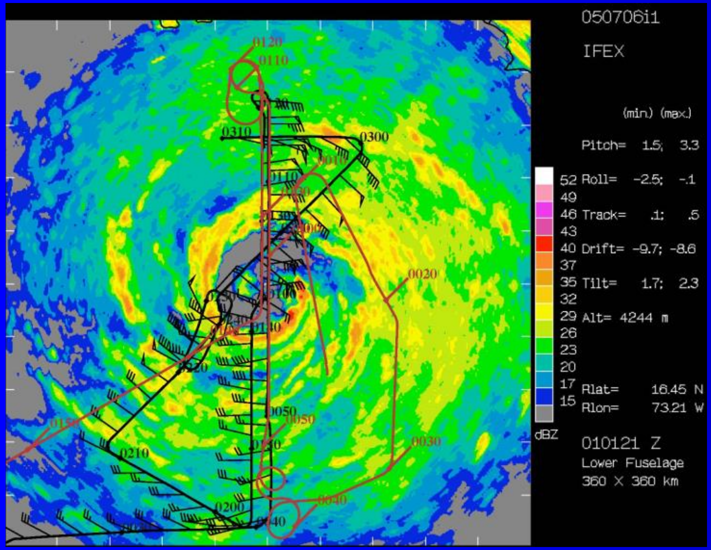
Reflectivity (dBZ)



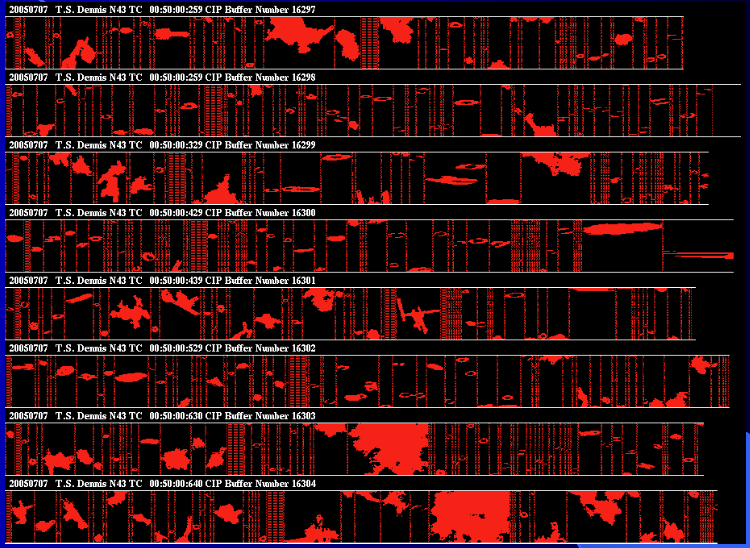
Scales sampled by Airborne Observations

Microphysical Structure

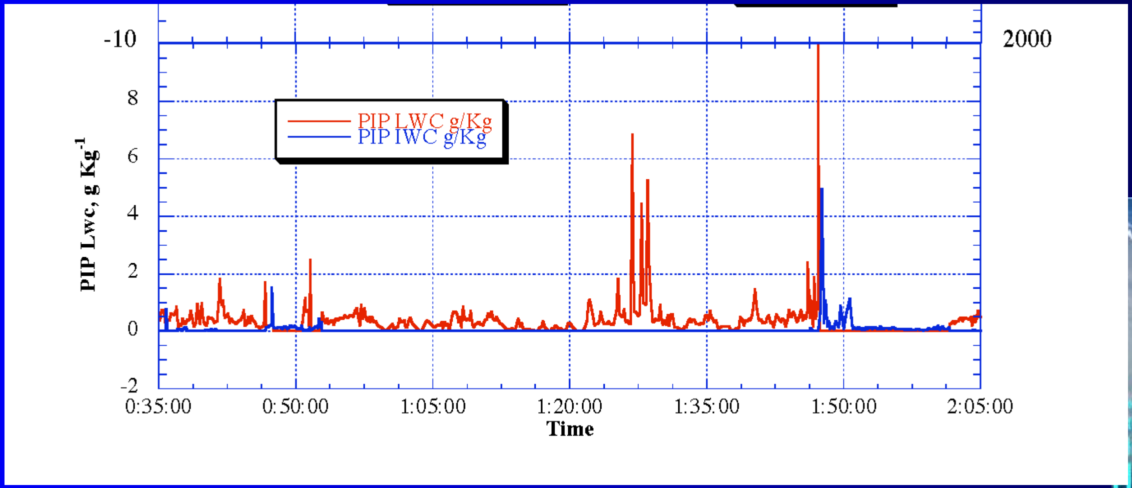
Flight track and LF image

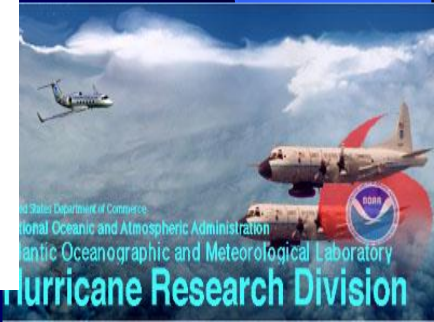


Cloud physics particle images



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.

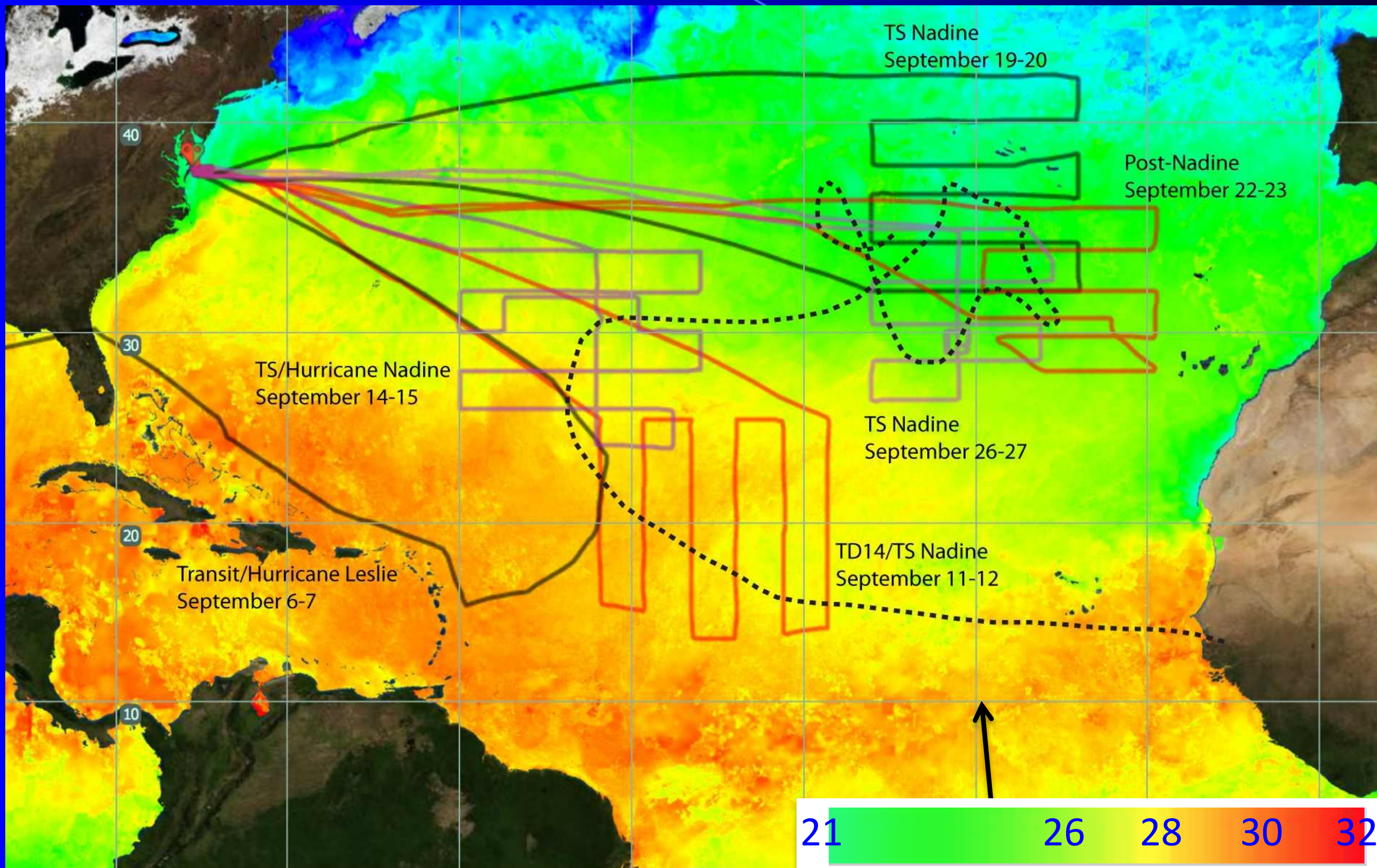
New Airborne Platforms

Global Hawk Operations Center (NASA Armstrong Base, CA)

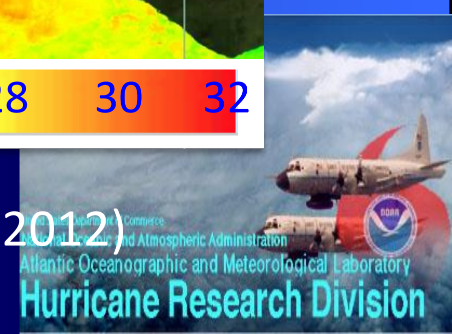
United States Department of Commerce
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
Hurricane Research Division

New Airborne Platforms

Long range of Global Hawk



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

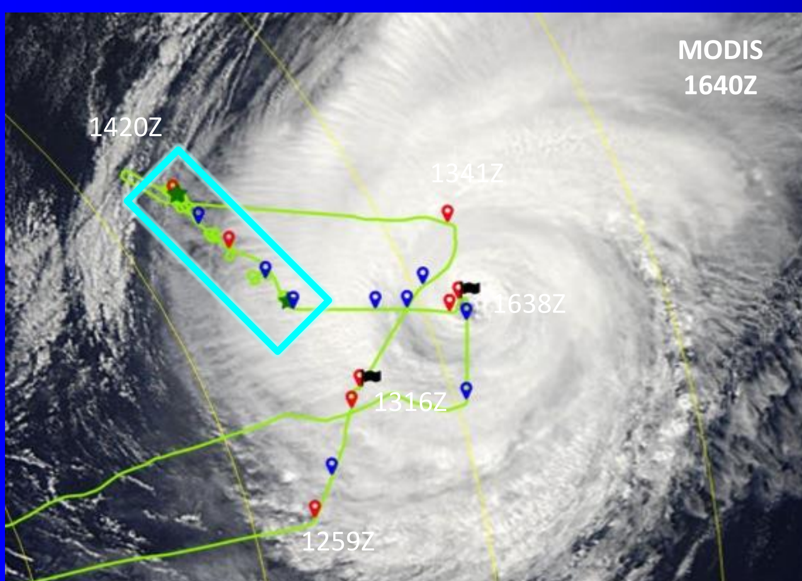


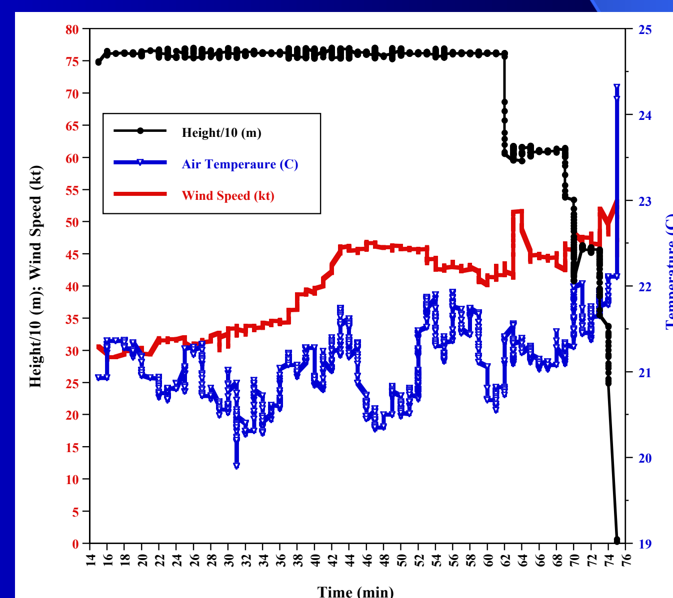
New Airborne Platforms

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)





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New Airborne Platforms

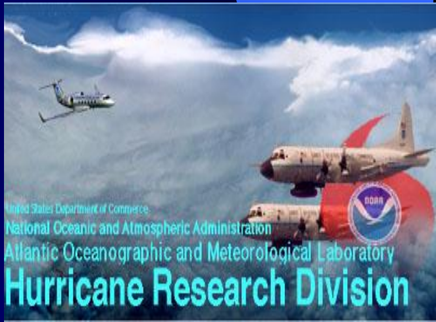
Depiction of Coyote launch

2. Use of observations to improve hurricane forecasts

- Improving the specification of the initial state of the atmosphere (Data Assimilation)

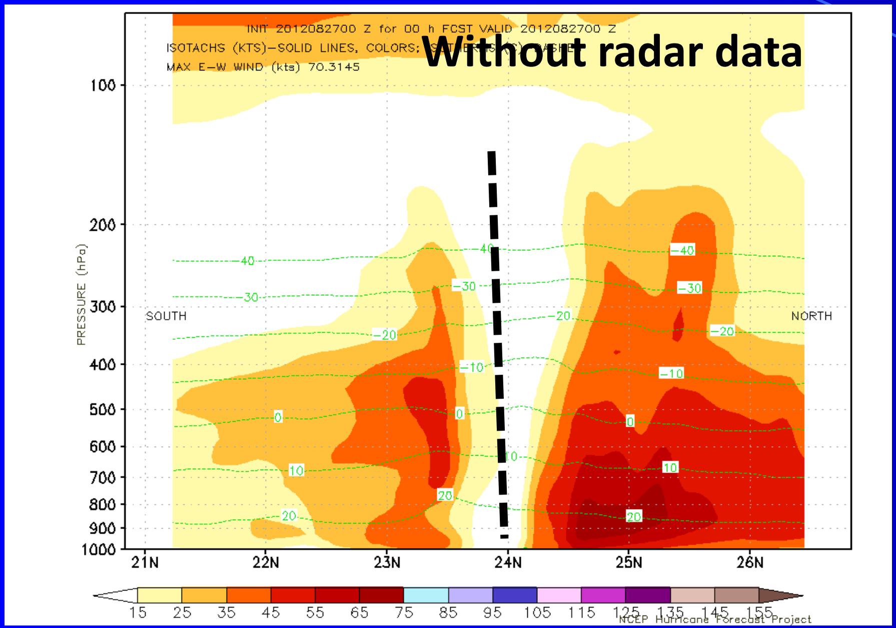
- Evaluating and improving the performance of numerical models (Model Evaluation)

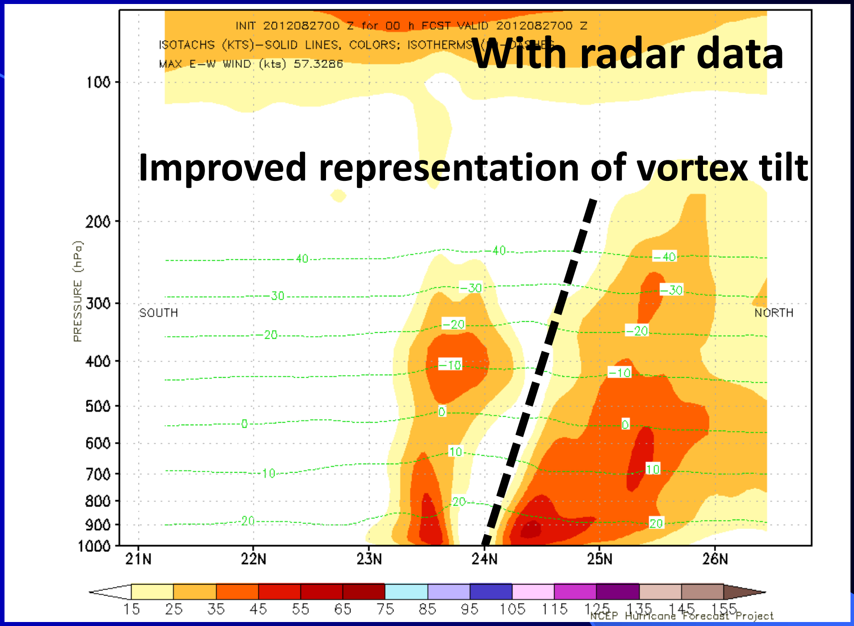
- Improving the understanding of tropical cyclone behavior (Hypothesis Testing)



Use of Observations – Data assimilation

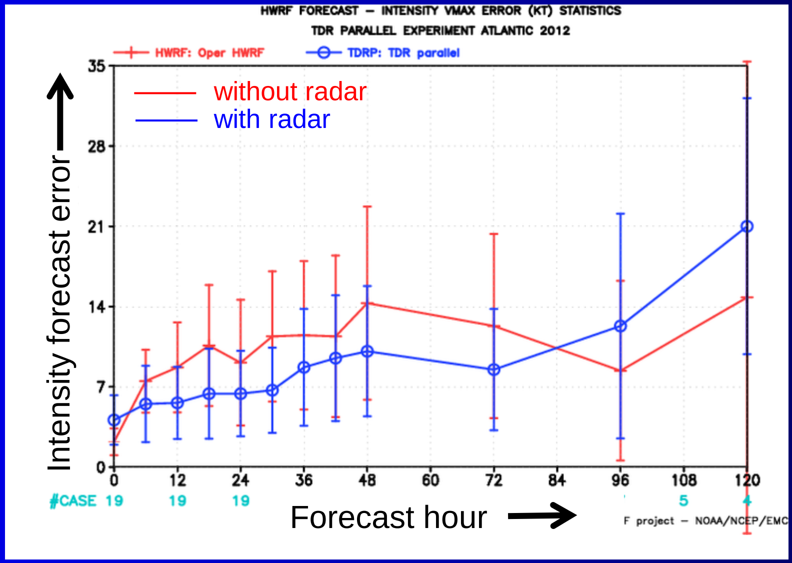
Vertical cross section of wind speed in Isaac (2012) at start of model forecast

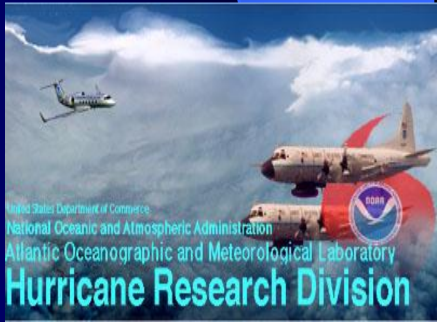




Impact of assimilating inner-core observations into forecast model

- **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)**



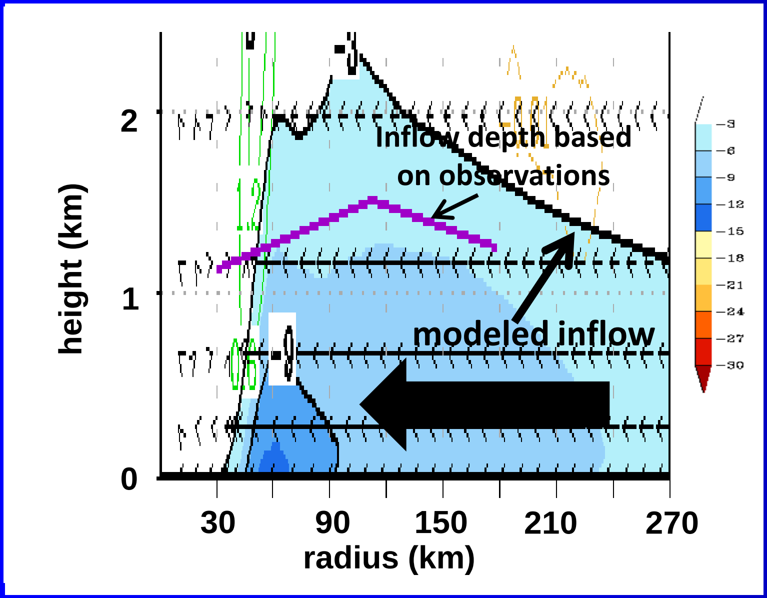


Use of Observations - Model evaluation

Sensitivity of radial wind to mixing processes in low levels

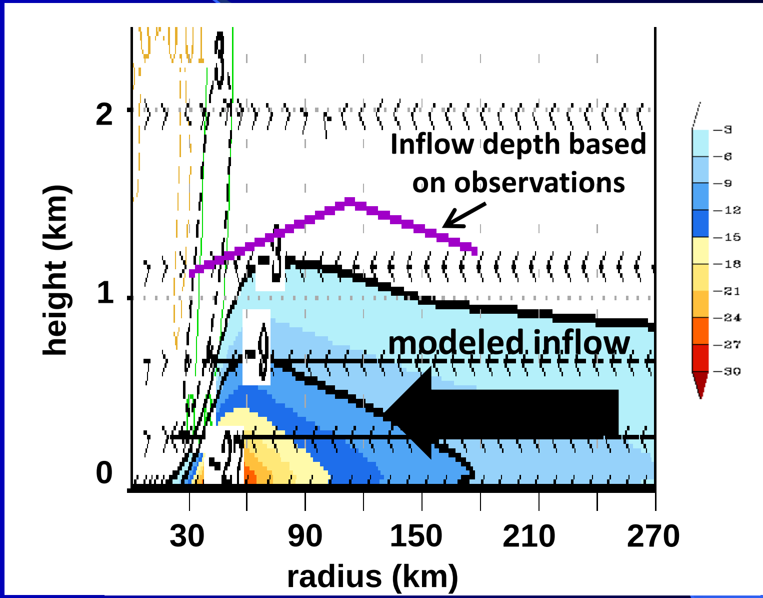
Radial inflow for different model runs

Old mixing version



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

New mixing version based on observations



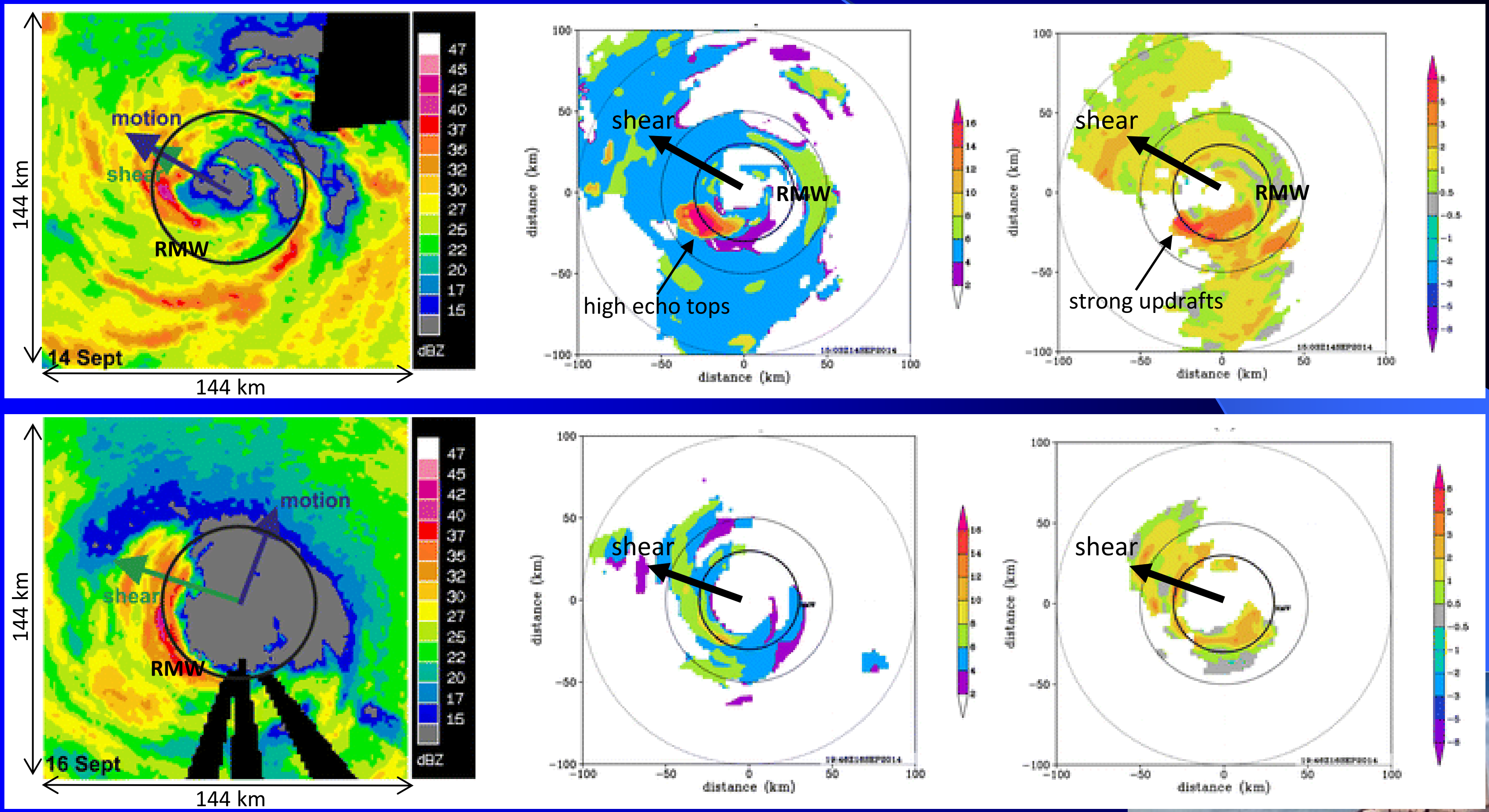
- peak radial inflow stronger with more accurate mixing
- depth of inflow layer more consistent with dropsonde composites using more accurate mixing

Use of Observations – Hypothesis testing

Hypothesis: TC intensification is favored when convection exists upshear inside RMW

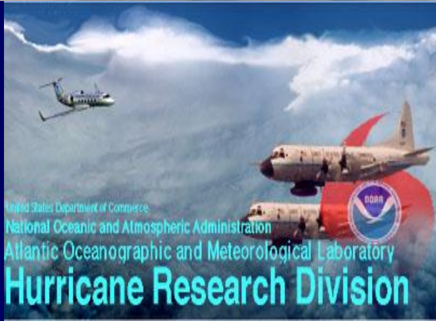
Reflectivity, echo tops, and upper-level updrafts in Hurricane Edouard (2014)

	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			

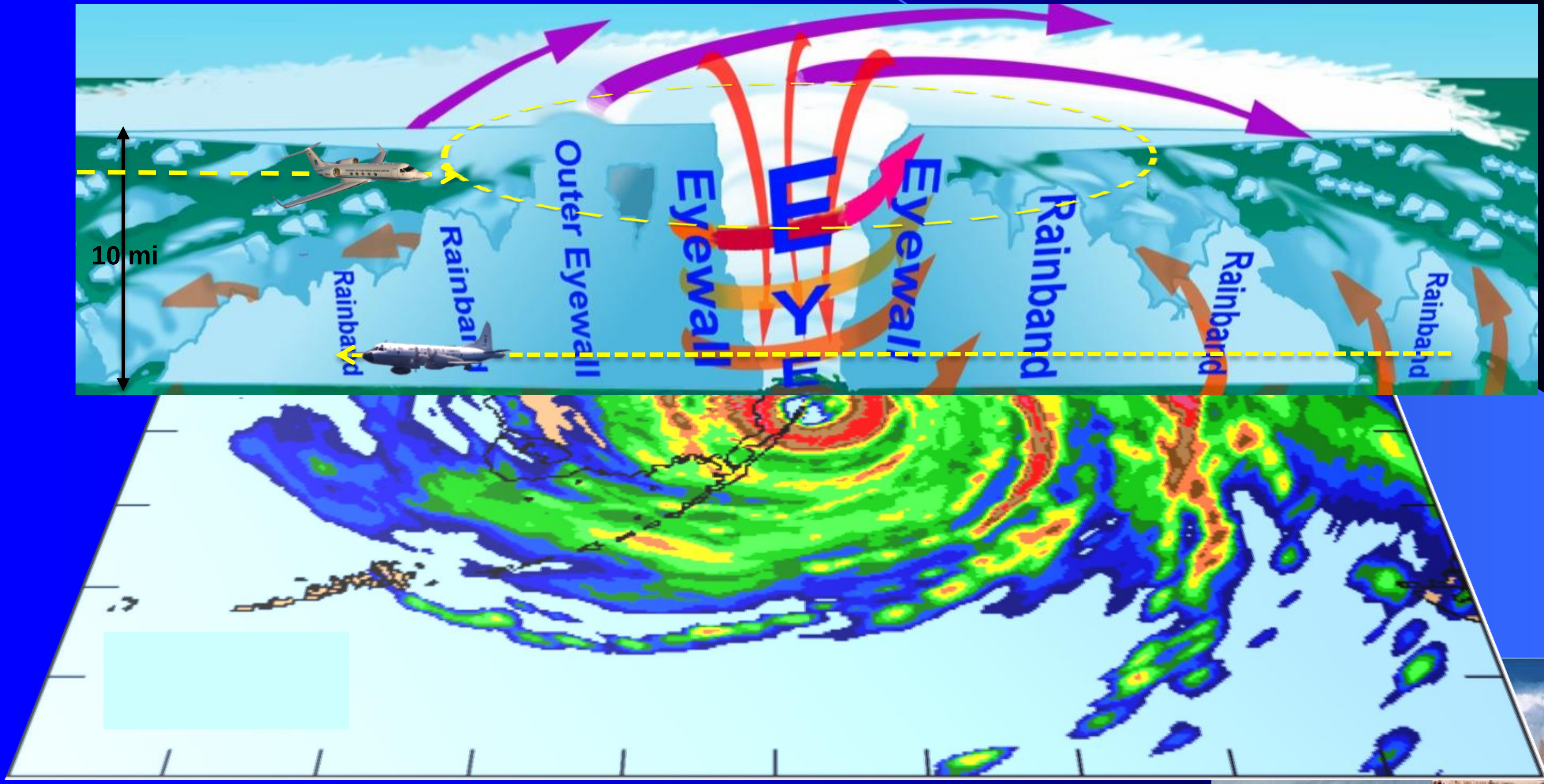


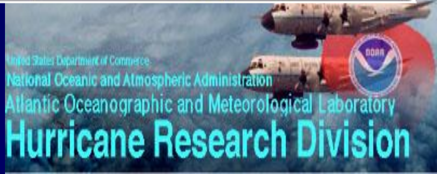
- 14 Sept (RI period): Strong updrafts, high echo tops upshear left and inside RMW
- 16 Sept (SS period): Weaker updrafts, mostly downshear left, at RMW
- Can we predict likelihood of persistence of convection upshear based on obs, model?

3. Flight profiles



Aircraft sampling of TCs

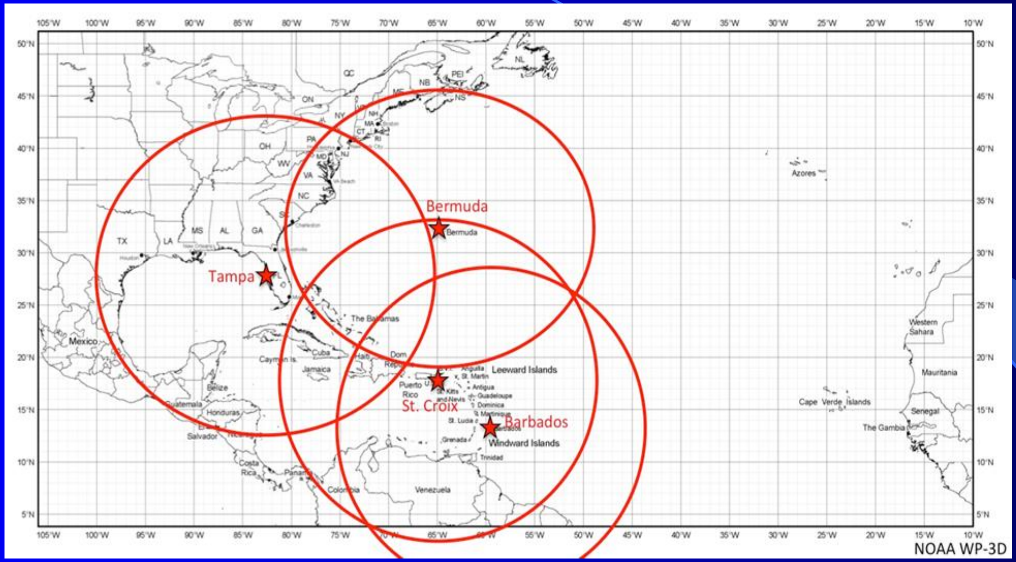




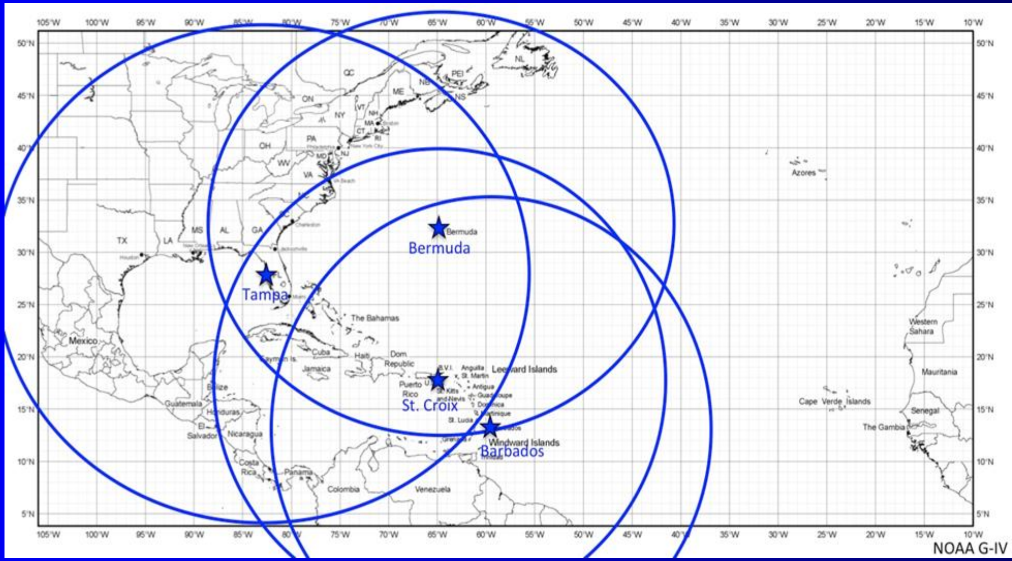
P-3 and G-IV Atlantic bases of operations

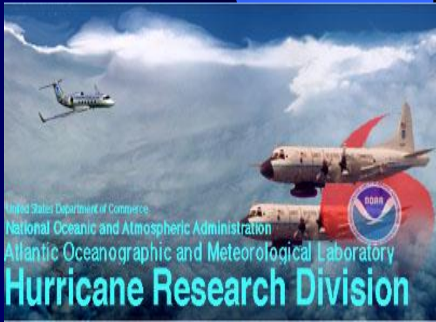
Assuming 2 hours of on-station time

P-3



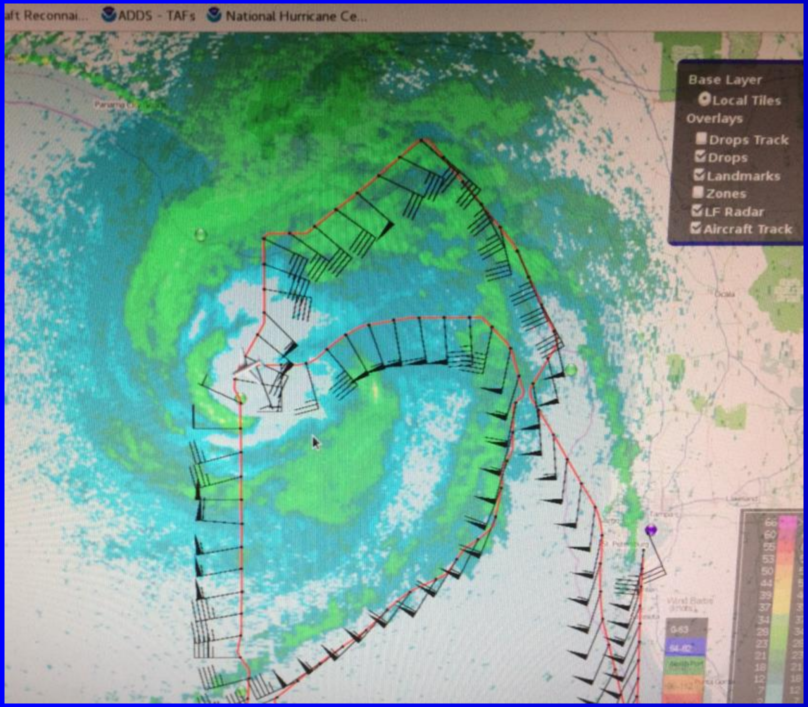
G-IV



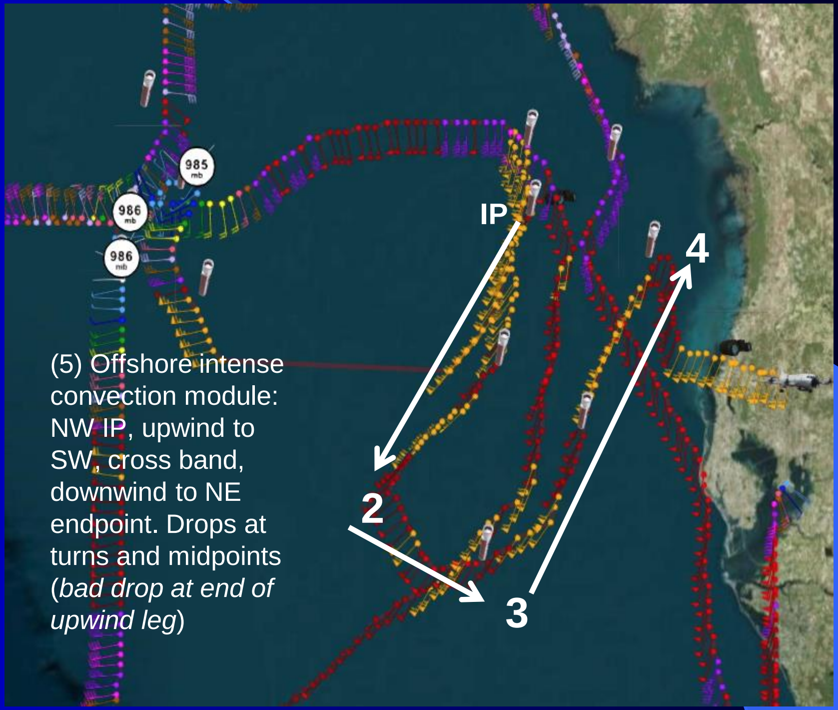


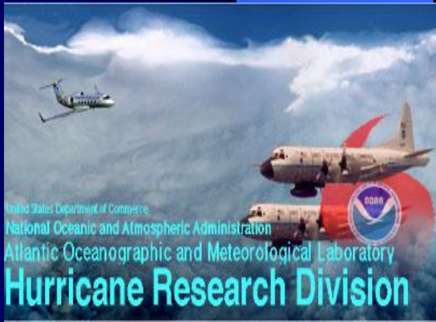
Sample P-3 Flight track into Hurricane Hermine September 1, 2016

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



Flight track and flight-level winds (kt)

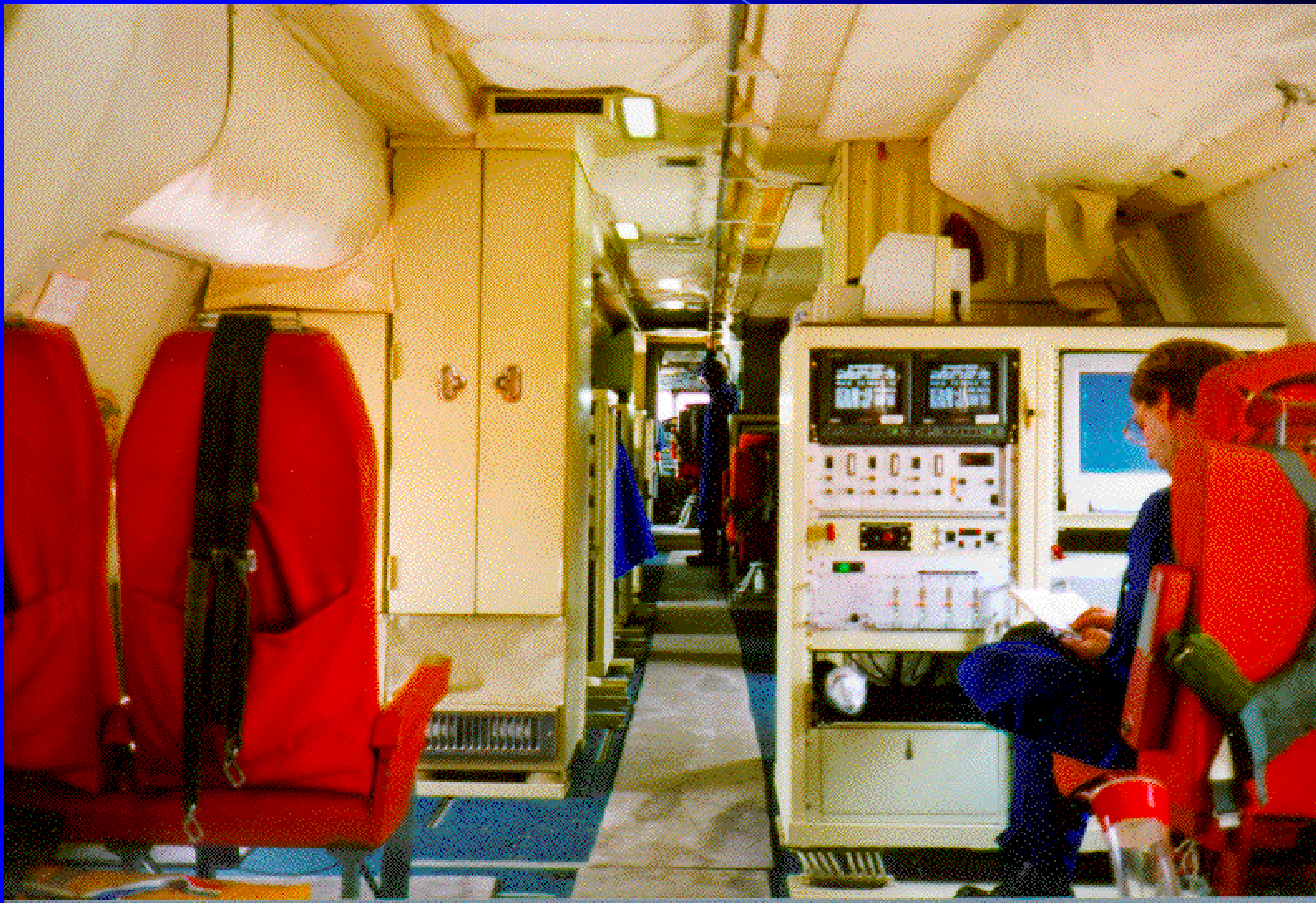




4. Views from the aircraft

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

Inside the P-3 Aircraft



Dropsonde release on P-3

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Atlantic Oceanographic and Meteorological Laboratory
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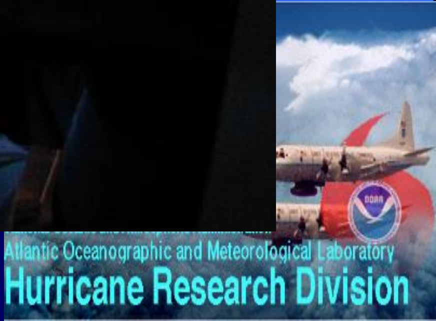
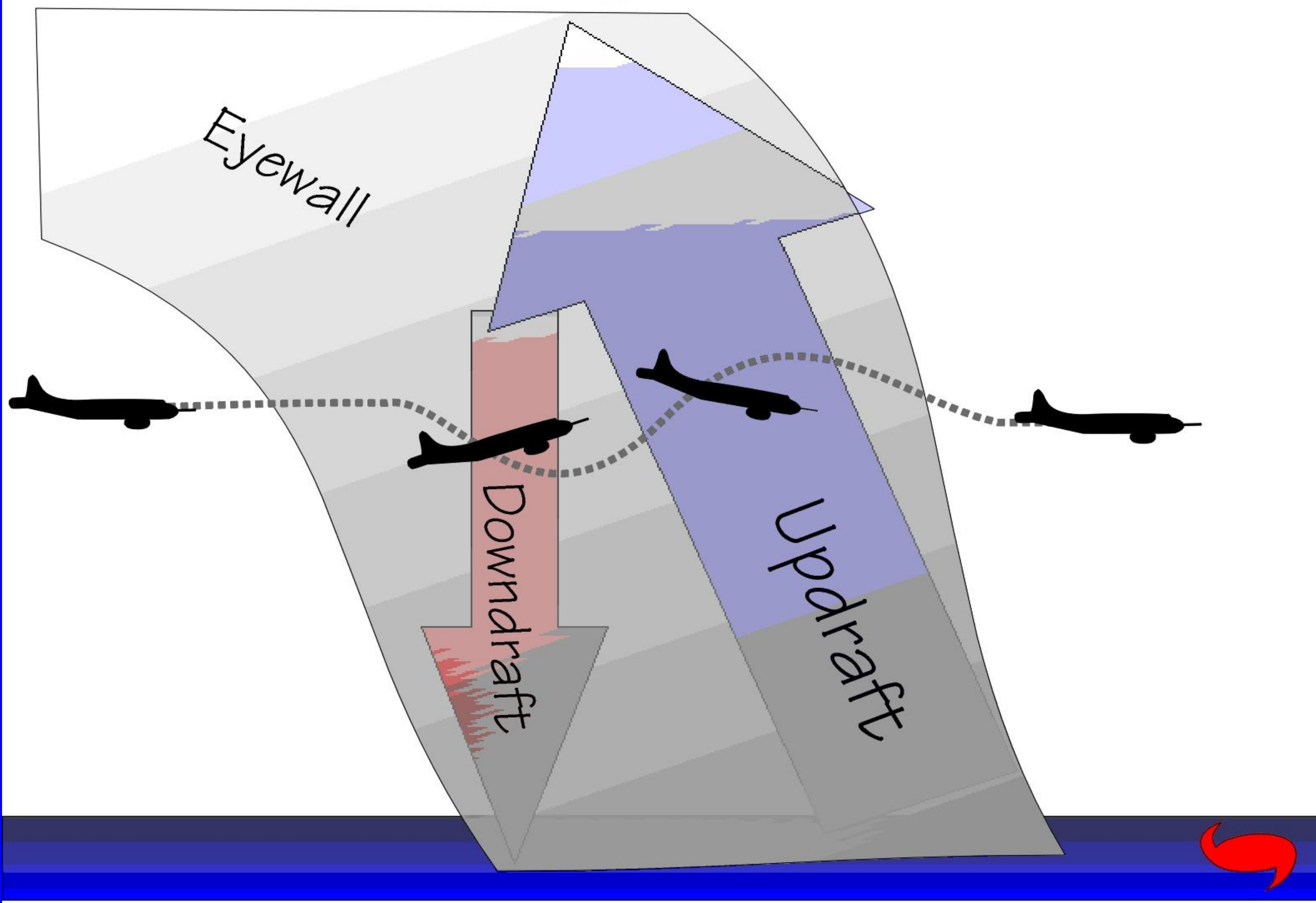
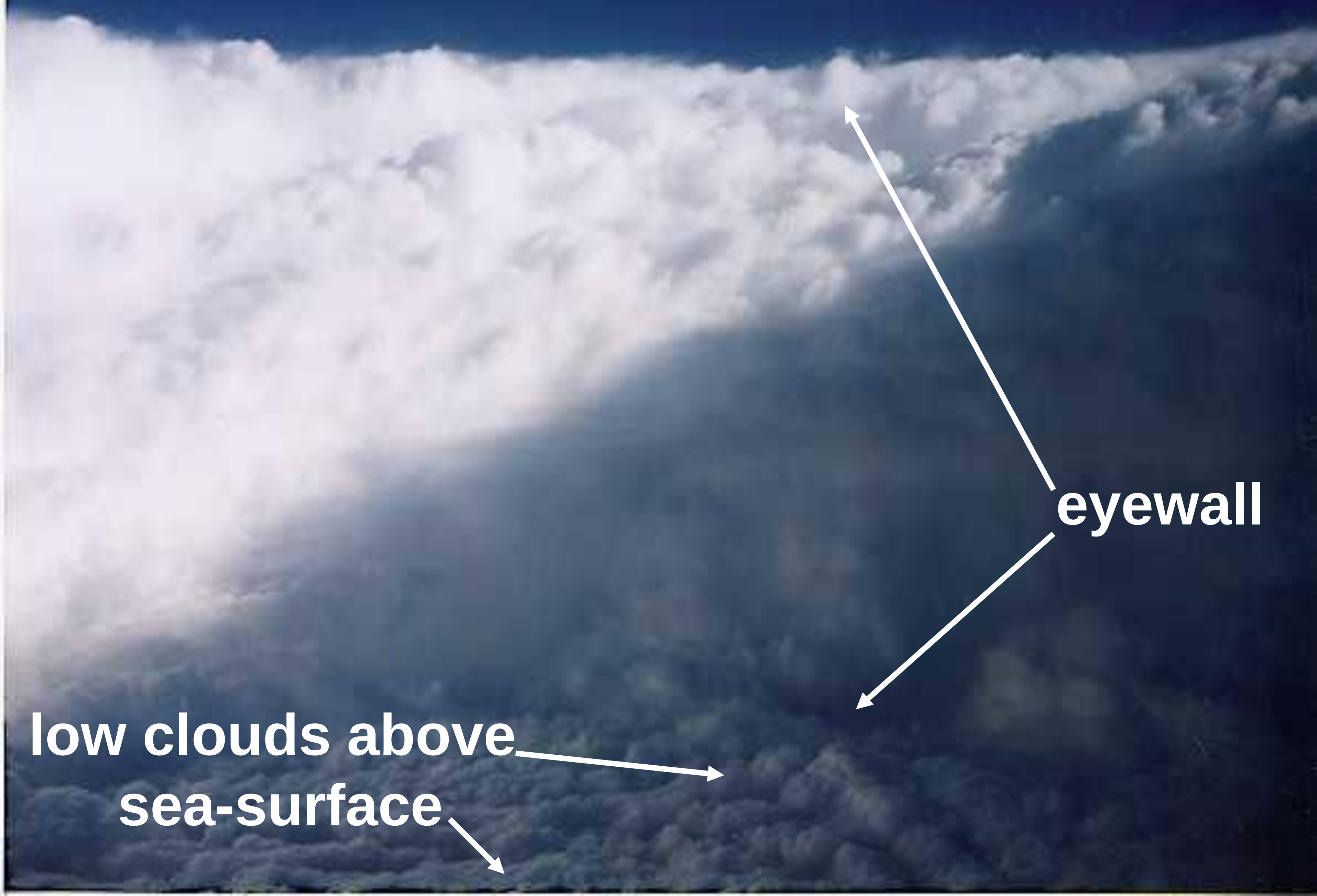
Inside the G-IV Aircraft



Hurricane Eye Penetration

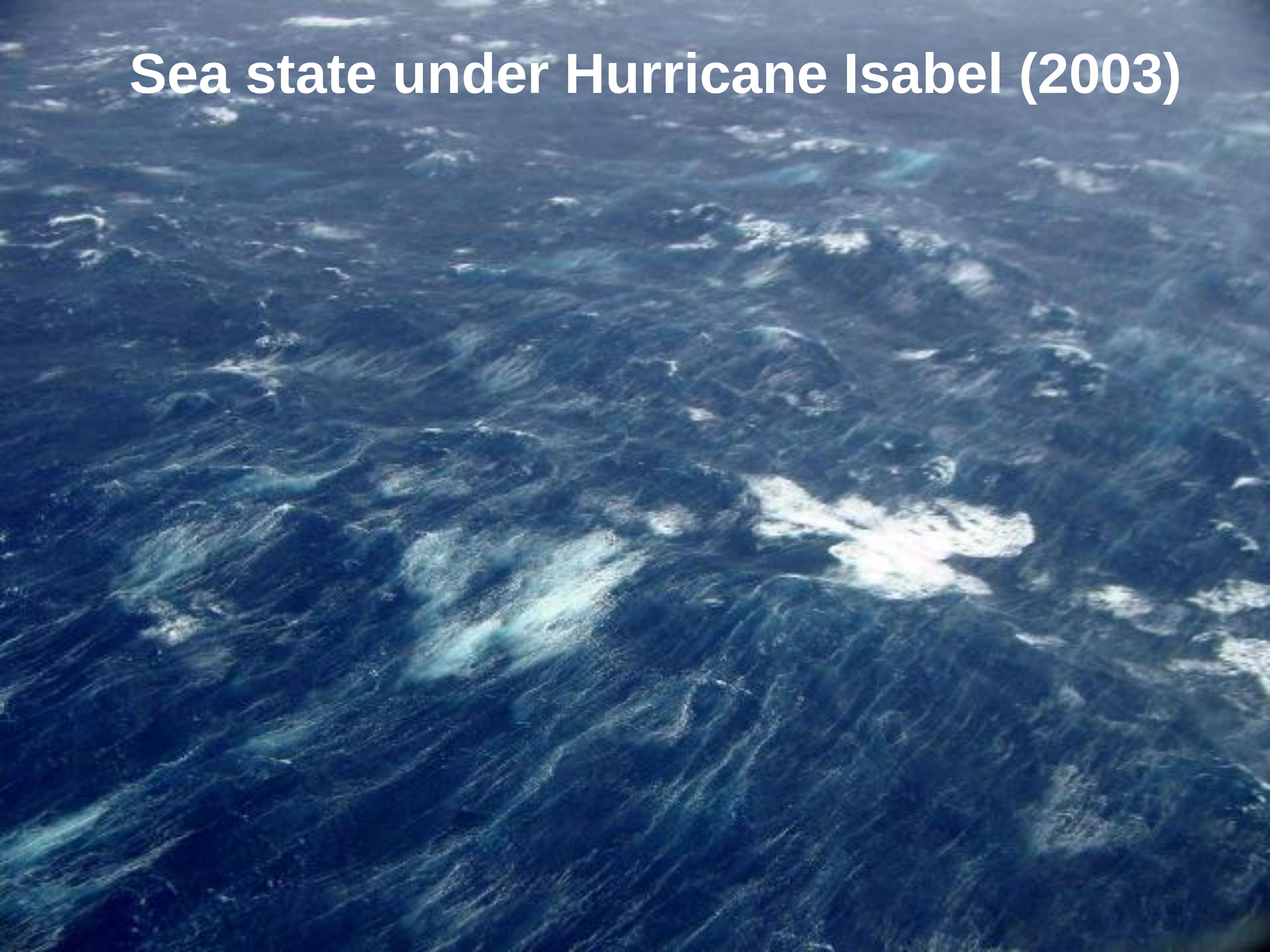


Within the Eye of Hurricane Georges (1998)



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!