Aircraft Observations of Tropical Cyclones



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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
- 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 Ospace Corporation in Savannah Georgia





Lower Fuselage (LF) Radar

LF image of Hurricane Ivan (2004)







Tail Doppler Radar





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GPS dropsonde



Eyewall Wind Speed Profiles Hurricane Guillermo - 3 August 1997





Scales sampled by Airborne Observations Environmental structure

Synoptic-surveillance using dropsondes



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



Scales sampled by Airborne Observations <u>Vortex Structure</u>

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





(c)

Vertical velocity (m/s)

Reflectivity (dBZ)

30

(b)

40

50

50.0

40.0

30.0

20.0 Zgp

10.0

0.0

10.0

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Scales sampled by Airborne Observations Microphysical Structure

Flight track and LF image



Clouds objects of the service of the

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)



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New Airborne Platforms Long range of Global Hawk



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

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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



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2. Use of observations to improve hurricane forecasts Intensity Forecasting Experiment (IFEX)

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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
- 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



Hurricane Harvey (2017)

#NOAAHurricaneAware



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





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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

2 on observations height (km) -12 -15 -21 1 -24 modeled inflow -27 -30 0 30 210 270 150 90 radius (km)

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



IFEX NOWCASTS: Improved representation of TC structure *Hurricane Lane missions (19-23 August 2018)*





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Provided by Heather Holbach

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 wi pressures, temperature, and moisture that satellites can not reliably measure
Aircraft have limited range and endurance, unlike satellites



Real-time display of reflectivity and winds in Hurricane Lane



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





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 ightning, indicator of deep convection Lightning located inside the radius of maximum wind Indicator of



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)



- 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?

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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

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



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P-3 and G-IV Atlantic bases of operations

Assuming 2 hours of on-station time



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NOAA G-IV

G-IV

September 1, 2016

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



Flight track and flight-level winds (kt)

(5) Offshore intense convection module: NW IP, upwind to SW, cross band, downwind to NE endpoint. Drops at turns and midpoints (bad drop at end of upwind leg)



4. Views from the aircraft

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Inside the P-3 Aircraft



Dropsonde release on P-3



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Inside the G-IV Aircraft



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Hurricane Eye Penetration



Within the Eye of Hurricane Georges (1998)

`eyewall

Iow clouds above____ sea-surface、

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



Thank you!