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
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

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

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

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

Radars on WP-3D
Tail Doppler Radar

outward-sloping eyewall
NCAR GPS Dropsonde

GPS dropsonde
the definitive atmospheric profiling tool

Square-cone Parachute increases stability of dropsonde

GPS Antenna

GPS Receiver collects data from GPS satellites to calculate wind speed and direction

Pressure sensor

Humidity sensor and temperature sensor

Sonde Dimensions
Length: 19.5
Diameter: 2.75
Weight: 0.86 lbs

Vents fill chute within 1.0 seconds after release from aircraft

Shock Cord reduces stress when chute opens

Microprocessor controls the transmitter and digitizes data from the sensors

Battery pack provides power for at least one hour

Radio Transmitter sends temperature, humidity, pressure, and GPS wind data to the aircraft every 0.5 seconds

Fall Speed ranges from 36 mph at 20,000 feet to 94 mph at sea level. A drop from 20,000 feet lasts 7 minutes.

Eyewall Wind Speed Profiles
Hurricane Guillermo - 3 August 1997

Height (m)

Wind Speed (kt)
Scales sampled by Airborne Observations

Environmental structure

- Synoptic-surveillance using dropsondes
- Steering flow
- Variation in moisture content of environment around hurricane
Highest rain rates normally in eyewall, mostly convective, cover small area.
Lighter rain rates in stratiform areas outside eyewall, cover larger area.

Vortex Structure

Double eyewalls seen from airborne radar.
Scales sampled by Airborne Observations
Convective Structure

Strong convection seen from radar

(a) ER-2 EDOP

(b) ER-2 EDOP

(c) P-3 TA

(d) P-3 TA

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

New Airborne Platforms

Global Hawk Operations Center (NASA Armstrong Base, CA)
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)**

IFEX intended to improve prediction of TC intensity change by addressing three goals:

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

Rogers et al., BAMS, 2006

Rogers et al., BAMS, 2013
IFEX FORECASTS:
Assimilation of data into numerical models

#NOAAHurricaneAware

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

4 P-3 missions
24-26 August

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

- 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)

Provided by Heather Holbach
Real-time displays of flight-level winds and aircraft “fixes” for Lane

IFEX NOWCASTS:
Improved representation of TC structure

• 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

Hurricane Lane (2018)

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

Courtesy Stephanie Stevenson, NHC
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
Reflectivity, echo tops, and upper-level updrafts in Hurricane Edouard (2014)

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

**IFEX RESEARCH**: Improve understanding of vortex intensification in shear.
**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

~1200 sondes used
3. Flight profiles
Aircraft sampling of TCs
P-3 and G-IV Atlantic bases of operations

Assuming 2 hours of on-station time
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)

(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
Inside the P-3 Aircraft
Dropsonde release on P-3
Inside the G-IV Aircraft
Within the Eye of Hurricane Georges (1998)

- eyewall
- low clouds above sea-surface
In the Eye of the Hurricane Isabel (2003)
Sea state under Hurricane Isabel (2003)
Low-level flight
Stadium effect
Impressed scientists
Thank you!