Recent Progress in Tropical Cyclone Intensity Change Through Aircraft Field Campaigns

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EXperiment on Typhoon Intensity Change in Coastal Areas (EXOTICCA)
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Intensity Forecast Experiment (IFEX)
Observing platforms and instruments

- In-situ
  - Wind, press., temp.
  
- Expendables
  - Dropsondes
  - AXBT, AXCP, buoy

- Remote Sensors
  - Tail Doppler Radar (TDR)
  - SFMR/HIRAD
  - WSRA
  - Scatterometer/profiler
  - UAS

NOAA P-3s

NOAA G-IV

NASA Global Hawk

G-IV Tail Doppler Radar

Coyote UAS

Doppler Wind Lidar

GPS Dropsonde

NCAR GPS Dropsonde
the definitive atmospheric profiling tool

G-IV Tail Doppler Radar
EXPERIMENTS- NOAA-HRD IFEX(2010-20)
Atmospheric/ Oceanic Measurement Systems

1. WP-3D
   a. Tail Doppler Radar (TDR)
   b. Doppler Wind LIDAR (DWL)
   c. Stepped Frequency Microwave Radiometer (SFMR)
   d. Imaging Wind and Rain Profiler (IWRAP- scatterometer/ Doppler profiler)
   e. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
   f. COYOTE mini-UAV deployment
   g. AXBT, AXCTD, AXCTD ocean profiling system
   h. ALAMO continuous ocean float deployment

2. G-IV
   a. Vaisala RD-94/ EOL mini-dropsonde Advanced Vertical Atmospheric Profiling System
   b. High-Altitude Tail Doppler Radar (TDR)
   c. Narrow-Beam, High-Altitude Stepped Frequency Microwave Radiometer (SFMR)
IFEX Goal 1: Assimilation of data into models

Impact Of Aircraft Observations On HWRF Forecast
- Improving Storm Structure At Initial Time -

The Hurricane Research Division of AOML developed a state-of-the-art inner core data assimilation system for HWRF (HEDAS) [Runs in real-time under HFIP]

<table>
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<th>ISAAC (2012): Intensity Errors (kt)</th>
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<td>Operational HWRF</td>
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<td># Cases</td>
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IFEX Goal 2: Develop & refine observing technologies: G-IV TDR

- 2 P-3 and G-IV flight track in Hurricane Edouard 15 September 2014

  - G-IV Doppler can provide enhanced coverage, especially at higher altitude
  - G-IV can be flown further from center to sample environment and supplement P-3, or closer to center to “replace” P-3
EXPERIMENTS: NASA HS3*(2012-14)  
ONR TCI**(2014-15) NOAA SHOUT***(2015-16)  
Atmospheric/ Oceanic Measurement Systems

1. NASA GLOBAL HAWK UAV  
   a. HAMSR  
   b. Cloud Physics LIDAR (CPL)  
   c. S-HIS  
   d. HIWRAP  
   e. EOL mini-dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS3)

2. NASA WB-57  
   a. High-Definition Sounding System (HDSS) for eXpendable Digital Dropsonds (XDDs)  
      for SST and rapid-release atmospheric profiling  
   b. Hurricane Imaging RADiometer (HIRAD)

*HS3- Hurricane and Severe Storms Sentinel  
**TCI- Tropical Cyclone Intensity  
***SHOUT- Sensing Hazards with Operational Unmanned Technology
NASA Hurricane and Severe Storm Sentinel (HS3):

- Science Goal: To understand hurricane genesis and intensification. NRL focused on hurricane outflow, dynamics, and predictability.
- 5-week deployments in hurricane seasons of 2012-2014 using two Global Hawks.
- Operational Implementation (SHOUT)

ONR Tropical Cyclone Intensity (TCI):

- Science Goal: To understand hurricane outflow dynamics and relationship to intensity.

High Definition Sounding System (HDSS):

- Innovative eXpendable Digital Dropsonde (XDD) atmospheric profiling system (YES, Inc.)
- Profiles of pressure, temp., RH, winds, SST
- Capable of rapid sonde deployment (50+)
HYPOTHESIS

TC Life Cycle, including Rapid Intensification (RI) and Rapid Decay (RD), is associated with environmentally-forced and inner-core convectively-forced outflow jet evolution:

I. TC development - Single Equatorward-directed Jet
II. Intensification and RI: Dual Equatorward and Poleward Jets
III. Mature & decay (ET): Primarily, single Poleward-directed Jet
Nadine

Pre-Gabrielle

0240-0435Z
2240-0035L

4 Sept 18Z, 14L
5 Sept 00Z, 20L
5 Sept 06Z, 02L
Phase II

Sonde plots courtesy Scott Braun, NASA Goddard

Rapid-Scan AMVs courtesy CIMMS

Phase I

Edouard
200 mb
15 Sept 00Z

Phase II

Edouard
200 mb
17 Sept 00Z

(Sonde plots courtesy Scott Braun, NASA Goddard)
(Rapid-Scan AMVs courtesy CIMMS)
Composite Structure At Peak Intensity
Hurricane Edouard on September 16-17

Relative Humidity at 700 hPa
Valid for reference time of 00Z Sept. 17
NOAA SHOUT 2015

• **GOAL**: Test prototype UAS concept of operations that could mitigate the risk of diminished high impact weather warnings in case of polar-orbiting satellite observing gaps

• **Global Hawk**
  • Flight level: ~55-60,000 ft
  • Duration: ~24 h
  • Range: 11,000 nm
  • Payload: 1500+ lbs
  • Deployment site: NASA Wallops
  • 5 week deployment (late Aug through Sep)
  • Instrumentation: AVAPS, HAMSR, & HIWRAP
  • One successful storm flight in 2015 (due to El Nino effects)
  • Extend project into 2016
**XDD FACT SHEET**

### Physical Specifications
- **Weight**: 58.0 g (2.0 oz)
- **Diameter**: 6.6 cm (2.6 in)
- **Length**: 17.8 cm (7.0 in)
- **No parachute**

### Observables
- Temperature
- Humidity
- Pressure/ altitude
- Wind speed/ direction
- Vertical velocity
- Sea Surface Temperature
- Photo documentation
- Dual fall speeds:
  - Fast/ ballistic: 11min to splash
  - Slow/ spiral dive: 18 min to splash

### SODA can (full):
- **Weight**: 340 g (12 oz)
- **Diameter**: 6.4 cm (2.5 in)
- **Length**: 12.1 cm (4.75 in)

### RD-94
- **Weight**: 320 g (11.3 oz)
- **Diameter**: 7.0 cm (2.75 in)
- **Length**: 40.5 cm (15.9 in)
- **12” square cone parachute**

### Comparisons
- **AVAPS Mini**
  - **Weight**: 165 g (5.8 oz)
  - **Diameter**: 4.7 cm (1.8 in)
  - **Length**: 30.5 cm (12.0 in)
  - **8” square cone parachute**

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**XDD**

**SODA**

**AVAPS**

**RD-94**
1. 2 Automatic Dropsonde Dispensers (ADDs)
2. 2 receivers per ADD- 4 receivers total, 2 redundant backup
3. 4 antennas on WB-57
   a. 2 antennas on belly pallet
   b. 1 antenna on each wing tip
4. 5 Channels per receiver
5. 8 XDD’s per CH
6. 2x2x5x8 = 160 XDD signals (80 XDDs: 100% redundancy)
7. 1 CPU per CH = 10 CPUs for gain adjustment (volumn control)
8. Minisonde: 8 receivers x 1 sonde/receiver = 8 sondes, 0% redundancy

BOTTOM LINE: REVOLUTION IN SONDE DESIGN
New world for sampling strategies
Hurricane Imaging Radiometer (HIRAD)

- A passive microwave radiometer (C-band, 4 frequencies), similar to SFMR: Measures emissivity and retrieves hurricane surface wind speeds and rain rates over a wide-swath:
  - Swath Width ~ 60-80 km
  - Resolution ~ 1-5 km
  - Wind speed ~10 – 85 m/s
  - Rain rate ~ 5 – 100 mm/hr

- Synthetic Thinned Array Radiometer (*not mechanically scanning*) sees a wide swath below the aircraft

- Flight History:
  - Hurricane Earl (2010 GRIP, WB-57)
  - Hurricane Karl (2010 GRIP, WB-57)
  - HS3 2012 Pacific Flight (AV-1)
Microwave 91GHz Tb SSMIS  

HIRAD 4GHz Tb  
15 Oct

HIRAD image courtesy Dan Cecil, NASA Marshall
What is SFMR?

- **Stepped-Frequency Microwave Radiometer**
- Measures sea surface wind speed below aircraft
- Installed on tropical cyclone-penetrating aircraft
  - 2 NOAA WP-3D since 2004
  - 10 Air Force Reserve WC-130J since 2009
  - NOAA G-IV (currently not operational)
Highest SFMR Surface Wind EVER: 86 m/s 30 sec ave.
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWREP)

MEASUREMENTS GOALS:
Map the 3-dimensional winds and precipitation in precipitation regions associated with tropical storms.
Map ocean surface winds in clear to light rain regions using scatterometry.

HIWREP Characteristics:
- Conically scanning.
- Simultaneous Ku/Ka-band & two beams @ 30 and 40 deg
- New technologies in radar: low power solid state transmitters with pulse compression, single antenna
- GPM radar frequencies.
EXPERIMENTS- ONR TCS08 NSF TPARC(2008)
Atmospheric/ Oceanic Measurement Systems

1. AFRC WC-130J
   a. Nose C-band radar
   b. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
      a. Stepped Frequency Microwave Radiometer (SFMR)
      c. Mini-met/ SVP drift buoy deployment
      d. Lagrangian profiling float deployment
   e. EM-APEX profiling floats
   f. AXBT’s
   g. Alamo minni-float deployment
2. NRL/ NCAR P-3
   1. ELDORA Tail Doppler Radar
   2. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
3. DLR Falcon
   a. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
4. DOTSTAR ASTRA twin-jet
   a. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
WC-130J Ocean Sensor Deployments

Drifters - Floats

MOOS
NRL Mobile Ocean Observing System

AXBT/Launcher
Similar to TCS08 STY Jangmi RI/RD episode

- Jangmi Rapid Intensification/Decay Coincides with passage over warm/cold eddy pair prior to Taiwan landfall
- ITOP/TCS10 STY Megi undergoes RI over large D26 and OHC26 region
Rapid Structure Change
STY Jangmi

Result:
Ocean eddy pair interacts with storm dynamics to produce immediate rapid decay and structure change prior to landfall.
Mesoscale eyewall features:
Unknown effects on ocean forcing
STY Megi 17 Oct

COSMO SKYMED-3 SAR: 0925 UTC

WC-130J C-band Weather Radar: 1115 UTC
Never-before seen
Boundary-layer features

1. Winds to the surface, 4m
2. Super-adiabatic surface layer, <40 m
3. Constant radial and total wind speed, sfc to 40 m; violates log
4. Highest sonde wind ever: 110m/s
5. Highest sonde sfc wind ever: 90m/s
The AXBT Demonstration Project
Observing the Oceans Around TCs

**Overall Objective:**
*Increase hurricane forecast accuracy by assimilating ocean observations from beneath tropical cyclones into coupled numerical models in near-real time*

**Incremental Objectives:**

1. Collect, process, and transmit AXBT data to coupled modeling centers in near-real time
2. Assimilate AXBT data into coupled models
3. Demonstrate improvement to ocean model initializations and forecasts
4. Demonstrate improvement to hurricane track and intensity forecasts
Deployment Activity during the 2014 Season

20 July – 15 September 2014
6 personnel
3 Midshipmen, 2 Officers, 1 NCO
257 AXBTs deployed

42 flights with 53rd WRS
- Hurricane Bertha (5)
- Hurricane Iselle (7)
- Hurricane Julio (5)
- Hurricane Cristobal (10)
- Other invests (2)
- Transits/Training (13)

- 20 July – 15 September 2014
- 6 personnel
- 257 AXBTs deployed
Upper-ocean temperature characteristics

- Close proximity of the storm tracks provided a unique opportunity to repeatedly sample multiple locations
- Generally, SST: 25-26.5°C and MLD: 50-75m
- Mixed layer cooled up to 1°C and depth varied by 20m between 7-10 August, then warmed prior to the 12 August wake flight.
**ALAMO**

Smaller profiling float that will fit in the AXBT launcher and can be used operationally by the USAF and NOAA Hurricane Hunter planes.

Advantages over AXBT include: multiple profiles, more sensors (pressure, salinity, & accelerometer for surface waves), no VHF receiver equipment on planes

A-sized case

Weight ~10 kg

1200-meter depth rating

1–2 dbar bin-averaged data

Iridium data communication

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**MRV SYSTEMS**
Deployed through the AXBT launch tube.

Previous air-deployed profiling floats have required opening tail ramp.
A-sized profiling floats were originally developed under funding from ONR, and redeveloped under NOAA Sandy Supplemental funding.

The ALAMO and Lagrangian floats have been tested and deployed in cooperation with USAFR 53rd WRS.
Float 9035, WMO #4901723

Deployed East of Hawaii, Hurricane Iselle

Reported 8 profiles per day from Aug 8 to Nov 25

Profile depth varied from 200 to 300 dbar
Air-Deployment by 53rd Hurricane Hunter Squadron of Air National Guard
Atmospheric Pressure Comparison: Drifters vs. Dropwindsondes (Rita, 2005)
Gradient Wind Balance above Boundary Layer: Comparison with Dropsonde wind speed

Rita wind speed

- all dropsondes
- dropsondes within drifter swath
- gradient wind from drifter pressure obs

wind speed (m/s)

distance east of center (km)

Dropsondes 1500–2000m av, N=243
Rita wind directions

Nplot= 749, days 264.7–268.0 = 3.3, 9/21/2005 – 9/24/2005, Nskip= 4

Dropsondes 0–50m av, N=216
Stages in Field Program Development
HFIP HS3 TCI EXOTICA

- Conception, design, vetting- 2 yr
  - All-inclusive, multi-scale concept design
  - Multi-purpose, sub-module conceptualization
- Focus down: 2-3 key modules (very important)
- Design, testing, dry run- 2 yr
- Trial implementation- 1 yr
- Operational demonstration- 2 yr
- Operational implementation- 10 yr