Emerging Airborne Observational Strategies for Improved Tropical Cyclone Prediction

Peter G. Black
I.M. Systems Group, Inc
In support of NOAA Environmental Modeling Center HFIP Team Meeting 20 February, 2019
National Center for Weather and Climate Prediction

Hurricane Florence: 12 Sep, 2018
International Space Station
Photos- ESA Astronaut Alexander Gerst

Peter G. Black
I.M. Systems Group, Inc
In support of NOAA Environmental Modeling Center HFIP Team Meeting 20 February, 2019
National Center for Weather and Climate Prediction
Presentation Objective
Provide some insight concerning the scope of airborne observations conducted on a operational basis for use in tropical cyclone model assimilation, especially sondes.

Outline of presentation
- Aircraft platforms used operationally and for numerical model DA in Tropical Cyclones (TC) impacting the U.S., Mexico, Caribbean and the Western Pacific
  - reconnaissance (inner core flights)
  - surveillance (environmental flights)
- Recent TC surveillance/ reco examples: Lane, Florence, Michael
- Florence forecast impact
- Recent WPAC dropsonde observations: DOTSTAR, China rocketsonde
- P3, GIV Tail Doppler Radar (TDR)
- Global Hawk/ high altitude manned aircraft innovative observations
- Summary
Emerging High Altitude Operational Airborne Technology

NASA

NOAA
Emerging Operational Airborne Technology Takes Flight in the U.S. AND THE WORLD
Hurricane Lane
Significance:
- First P3 Hawaii deployment
- First Hawaii 4-aircraft deployment
- First operational wave data - WSRA

Totals:
- 4 G-IV flts (120 sondes, ~30/flt)
- 4 WP-3D flts (63 sondes, ~16/flt)
- 5 WC-130J flts (35 sondes, ~7/flt)
- 5 NASA DC-8 flts (0 sondes)

18 flights over 7 days
218 sondes over 4 days
Hurricane Florence Brief

Flights/Sondes
- Nine (9) GIV surveillance flights/ 281 sondes (Ryan Torn targeting strategy)
- Three (3) WP-3D research flights / 82 sondes/ 13 good (20 deployed; 35% fail) AXBTs
- Eight (8) WC-130J reco flights/ 196 sondes (700 mb)/20 AXBTs on 5 flights
- Total sondes: 559
- Ten (10) Alamo floats deployed from WC-130J at 03Z 11 Sep; storm passage ~ 21Z 11 Sep

Hurricane Michael Brief

Flights/Sondes
- Three (3) GIV surveillance flights/ 87 sondes (Ryan Torn targeting strategy)
- Six (6) WP-3D research flights (2 post-storm)/ 102 sondes/ )/45 good (86 deployed; 48% fail) AXBTs / 18 AXCPs/ 11 AXCTDs
- Eight (8) WC-130J reco flights/ 81 sondes (700 mb)
- Total sondes: 270
- Eight (8) Scripps drifters, 3 EM-APEX floats deployed from WC-130J ahead of Michael on 9 Oct
Hurricane Florence
8-15 Sep 2018

Total flights: 20
Total Sondes: 559

Florence Track sensitivity 06Z, 10 Sep

WP-3D Tracks (3) and Sondes (82): below
WC-130J Tracks (8) and Sondes (196): below

GIV Tracks (9) and Sondes (281): right
ALAMO Float Deployment
Hurricane Florence
Hurricanes Florence and Helene

--Major Atlantic Basin Wake Cooling

--Hurricane Cold wakes ≤-1-3°C

--Major warm anomalies north of 30N
Hurricane Michael
8-10 Oct 2018

- P3 Tracks (5) and Sondes (102)
- WC-130J reco flights (8) and sondes (81 fromm 700 mb)
- Total sondes: 270

Michael Ocean Obs:
- WP-3D 6 AXBT flights (2 post-storm- red tracks):
  - 45 good AXBTs (86 deployed; 48% fail)
  - 18 AXCPs/ 11 AXCTDs
  - Eight (8) Scripps drifters, 3 EM-APEX floats
  - Deployed from dedicated WC-130J ahead of Michael on 9 Oct

GIV Tracks (3) and Sondes (87)
Take-away:

- Need to cover more times & territory, i.e. two G-V’s twice a day
- Need to fly higher, i.e. GLOBAL HAWK
**DOTSTAR ASTRA 2003-2017**
Flights: 80, TY : 64

**Launch location of Dropsonde by ASTRA Jet**

**Dropsonde:** 1325, Fail: 105 (8%)
*Outer Radius: 900km*

Po-Hsiung, C-C. Wu et al., AVAPS 2018

- 0-100 km (inner core) : 020
- 100-300 km (outer core) : 412
- 300-500 km (near environ): 497
- 500-900 km (far environ) : 254

**P3+GIV 1998-2010**
PBL TCs: 208
PBL Dropsondes: 1878
Outer Radius: 330km
Jun Zhang et al., 2013 MWR

**Launch Location of Dropsonde by ASTRA Jet**
Improvement of mean hurricane-track forecast in the GFS model as a result of assimilating G-IV synoptic surveillance dropsondes

Different Results from DOTSTAR Astra dropsondes in WPAC vs NOAA G-IV dropsondes in NATL

DOTSTAR sonde impact by NCEP GFS: 2003-2009 45 TCs (35 cases)
Track error reduction: 12-18%: 15% 24-36Hr UP to 18% 72-120 hr
Chou, et al., 2011 MWR

DOTSTAR sonde impact by CWB TWRF: 2008-2016 37 TCs (49 cases):
Track error reduction: only 6-8%
Po-Hsiung, C-C. Wu et al., AVAPS 2018

Improvement of mean hurricane-track forecast in the GFS model as a result of assimilating G-IV synoptic surveillance dropsondes

GIV 1999–2005
Track Skill Improve:
15% to 36hr, DOWN to 6% at 72 hr and 0% at 96 hr
June Wang et al., 2015 BAMS
Comparison of shear-relative drop composite wind profiles from DOTSTAR vs U.S.

June Wang et al., 2015 BAMS

Po-Hsiung, C-C. Wu et al., AVAPS 2018
U.S. Dropsonde PBL Composite TC tangential wind vs radius normalized by RMW, radius of maximum wind, for 4 TC quadrants relative to shear: DL- Downshear Left DR- Downshear Right UL- Upshear Left UR- Upshear Right

Zhang, et al., 2013
Scheme of the rocket dropsondes by COSIC and CMA since 2012

Revolver
3000 to 800 m/s

Reduction bin
800 to 100 m/s

Dropsonde
100 m/s to 15 m/s

Beat the swords into ploughshares
Overview of the dropsondedata
Background: Global Hawk (GH)

- GH has been used since 2010 for hurricane reconnaissance and surveillance
- Much longer range than manned aircraft
- Data from GH dropsondes has been shown to improve forecasts
- Dropsonde data from GH first used in HWRF in 2015
- Dropsonde data from GH first used in GFS in 2017
Global Hawk

SHOUT TCRR Operational Demo Observational Objectives
Sensing Hazards with Operational Unmanned Technologies (SHOUT)
Tropical Cyclone Rapid Response (TCRR)

Measure & Evaluate: transition from research (HS3) to operations (SHOUT)
Hurricane and Severe Storm Sentinel (HS3)

- Operational Impact on model predictions:
  - Hurricane intensity/ size/ structure change: \( V_{\text{max}}, P_{\text{min}}, \text{RR}, \text{RMW}, \text{R}_64, \text{R}_50, \text{R}_34 \)
  - Hurricane track change
  - Global Downstream Environmental Adjustment (Sipple, Tallapragada, Howard)

TC Model Real-Time Data Assimilation

- Improve targeting (timing/location/pattern) of *Real Time* dropsondes
- Optimal sonde input format, i.e. BUFR (full res) vs Temp Drop (single location)
- Techniques for data thinning/ super-obing (averaging) to match model resolution
- **Instrumentation strategy** for input to TC models: AVAPS/HIWRAP/HAMSR
  - High Altitude MIMIC Sounding Radiometer/High-altitude Wind and Rain Atmospheric Profiler
- In future: HIRAD (surface wind/ rain rate)- Hurricane Imaging RADiometer

Satellite GAP Mitigation for High-Impact Weather

- Operational Impact Studies for alternatives to satellite data
GLOBAL HAWK HS3 SHOUT 2012-2016

Track Skill IMPROVE non-Steady State: 20-30%
Track Skill DEGRADE Steady State: 0 to -10%
Intensity Skill IMPROVE non-Steady State: 10-20%
Intensity Skill IMPROVE Steady State: 0-5%

Christophersen, et al., 2018
Observational History - Global Hawk UAS
SHOUT/EPOCH 2015-2017

<table>
<thead>
<tr>
<th>Dates (2015)</th>
<th>Target</th>
<th>Duration (hours)</th>
<th># Sondes Deployed</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 26-27</td>
<td>TS Erika</td>
<td>23:43</td>
<td>14</td>
</tr>
<tr>
<td>August 29-30</td>
<td>TS Erika</td>
<td>23:44</td>
<td>58</td>
</tr>
<tr>
<td>September 5-6</td>
<td>TS Fred</td>
<td>24:00</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dates (2016)</th>
<th>Target</th>
<th>Duration (hours)</th>
<th># Sondes Deployed</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-13 February</td>
<td>Gaston</td>
<td>23.9</td>
<td>85</td>
</tr>
<tr>
<td>24-25 August</td>
<td>Gaston</td>
<td>23.8</td>
<td>55</td>
</tr>
<tr>
<td>29-30 August</td>
<td>Hermine</td>
<td>23.8</td>
<td>90</td>
</tr>
<tr>
<td>31 August – 1 September</td>
<td>Hermine</td>
<td>22.8</td>
<td>87</td>
</tr>
<tr>
<td>22-23 September</td>
<td>Karl</td>
<td>24.0</td>
<td>82</td>
</tr>
<tr>
<td>24-25 September</td>
<td>Karl</td>
<td>22.8</td>
<td>81</td>
</tr>
<tr>
<td>5-6 October</td>
<td>Matthew</td>
<td>24.7</td>
<td>62</td>
</tr>
<tr>
<td>7-8 October</td>
<td>Matthew</td>
<td>23.7</td>
<td>43</td>
</tr>
<tr>
<td>9-10 October</td>
<td>Matthew</td>
<td>24.8</td>
<td>63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dates (2017)</th>
<th>Target</th>
<th>Duration (hours)</th>
<th># Sondes Deployed</th>
</tr>
</thead>
</table>
SHOUT/EPOCH Flight & Sonde Observational History
(For additional details see AMS 33HURR Hock, Poster #4, Vömel, 5A.2)

- **2012-14**: NASA Hurricane and Severe Storms Sentinel (HS3) program: 21 research missions over 9 TCs
- **2015-16**: NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT): 15 Rapid Response (RR) flights: 3 in EPAC El Niño/Atmospheric River (AR) winter storm systems; 12 TCs
- **647 sondes in SHOUT**: all assimilated in ECMWF, UKMET, NAVGEM global models and HWRF, COAMPS-TC regional models.
- **2017**: East Pacific Origins and Characteristics of Hurricanes (EPOCH): 3 flights in 3 storms (GoM-Franklin, Harvey; EPAC- Lidia), **218 sondes total**: first Global Hawk minisonde assimilation in GFS
**System Name:** Global Hawk UAS High Impact Weather Surveillance & Reconnaissance Capability

**Instrument Capability:**
Airborne Vertical Atmospheric Profiling System (AVAPS)

*PI: Terry Hock, NCAR / Gary Wick, NOAA*

**Measurements:** REAL-TIME Assimilation
- temperature, pressure, wind, humidity (vertical profiles)
- 90 dropsondes per flight

**Resolution:**
- ~2.5 m (winds), ~5 m (PTH)

---

**High Altitude Monolithic Microwave Integrated Circuit (MMIC) Sounding Radiometer (HAMSR)**

*PI: Dr. Bjorn Lambrigtsen, JPL*

**Measurements:** Real-Time Display
- Microwave AMSU-like sounder;
- 25 spectral channels in 3 bands; (50-60 GHz, 118 GHz, and 183 GHz)
- 3-D distribution of temperature, water vapor, & cloud liquid water;

**Resolution:**
- 2 km vertical; 2 km horizontal (nadir)
- 40 km wide swath

---

**High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) Belly Doppler Radar**

*PI: Dr. Gerald Heymsfield, NASA GSFC*

**Measurements:** Real-Time Display
- Dual-frequency (Ka- & Ku-band), dual beam, conical scanning Doppler radar
- 3-D winds, ocean vector winds, and precipitation;

**Resolution:**
- 60 m vertical, 1 km horizontal;
Global Hawk Instrument Suite

HIWRAP Doppler radar profiler

AVAPS IMPACT:

HURRICANE GASTON TROPICAL CYCLONE UPDATE
NWS NATIONAL HURRICANE CENTER MIAMI FL AL072016
1215 AM AST THU AUG 25 2016

...GASTON BECOMES THE THIRD HURRICANE OF THE ATLANTIC SEASON...

Dropsonde data from a NASA/NOAA Global Hawk mission indicate that Gaston has strengthened to a hurricane. The maximum winds are estimated to be 75 mph (120 km/h) with higher gusts.

Matthew Warm Core HAMSR (54.4 GHz, ~150 hPa)

HIWRAP reflectivity cross section from TS Karl:
convective cores, high tops and extensive stratiform precipitation

AVAPS X-section Matthew 7 Oct

HAMSR passive microwave radiometric temperature and humidity profiler

Warm core of Matthew
HIRAD example
In the future for GH
Eyewall surface winds mapped
In 5 minutes

TCI 2015
Patricia
HIRAD wind swath
HDSS sfc wind (top)
HIRAD sfc wind (bottom)

Courtesy Dan Cecil, IHC 2017
QUESTIONS?