Advanced Dropsonde System for Hurricane Reconnaissance and Surveillance

Mark Beaubien, Yankee Environmental Systems, Inc.

Lee Harrison, Atmospheric Sciences Research Center, SUNY-Albany

Peter Black, SAIC - ONR Meteorology
Mission Goals

Operational hurricane reconnaissance

- Greatly increase time and spatial resolution within hurricanes to improve track and intensity prediction
- Improve reliability, flight safety, and costs over existing manned-operation dropsonde observations

Longer term

- Enable High Altitude Long Endurance UAV to carry and deploy large numbers of sondes automatically
- Change the economics of in-situ atmospheric profiling so that routine met parameters can be acquired over the oceans and land
HD Profiling
Customer Needs

- Reliability: Many RD-94 soundings have issues
- Safety: Lack of release automation requires Drop Sonde Operators to leave their seats
- SST: RD-94 only measures PTU+winds
- UAV: Automation and QC are needed for new remotely piloted *in-situ* observational strategies
- A “sounding technology refresh” is desired with overall system performance enhancements
XDD Dropsonde – 56 grams

Above: assembled,    Below: PCB with Antennas
HDSS Component Highlights

- eXpendable Digital Dropsondes (XDD) measure 4 Hz PTU+Winds, and SST via IR irradiance
- Automated Dropsonde Dispenser (ADD) magazine accommodates up to 48 XDD devices
- An integrated telemetry receiver subsystem tracks up to 40 XDDs in flight simultaneously via forward-error-corrected UHF digital telemetry

Represents the state-of-the-art for scientific quality, high spatial/temporal resolution soundings in terms of sondes released and simultaneously tracked
ADD Core System Design

◆ Single degree of mechanical freedom rotating selector drum guides one sonde into the drop tube
◆ Simple rotary failsafe air-lock can be halted by opening DC circuit to motor, removing system power, halt switch or sending command via TCP/IP
◆ Shaft encoder reliably positions drum, failsafe
◆ Proximity sensors detect jam conditions
◆ Optical link activates & QC’s sondes
◆ Air ejection, no parachute to catch
HDSS
Strengths/Advantages

- KISS principle: tight integration makes it reliable
- Improves operator safety while reducing human error
- High time resolution: 4 Hz PTU+Winds plus SST
- Automated Quality Control of XDD drops sondes
- Deploy XDDs as rapidly as one every 5 seconds
- Compatible with existing drop tubes, 28V, 400 MHz
- Cost: Far more data measurements per flight hour!
CIRPAS Twin-Otter Installation
We had an ideal marine boundary layer structure ...

CIRPAS Intercomparison Goals

- Ensure PTU+W accuracy is on par with RD-94s
- Blind test (RD-94 data was not shared)
- Test multiple devices across two flight days
- Compare XDD against:
  1. Multiple Vaisala RD-94s (latest design)
  2. NDBC ocean buoy (Winds, Ta, SST)
  3. Instrumented Twin Otter aircraft (Winds, SST)
- Two minute turns, centered over NDBC buoy
- Start at 12,000’ descending 500’ / minute to 100’
**Good Flight Test Results**

- Obtained 14 intercomparisons (RD-94/buoy/AC) over two flight days 6/24/11 and 6/25/11
- Overall reliability within 1% of RD-94 (~85%), and results identified clear engineering improvements
- 100% successful rapid fire mode (4 in ~20 secs)
- Some data received while floating on the water!

*Better than we expected … here’s what Dr. Peter Black, ONR Marine Meteorology reported:*
Conclusions of Peter Black, ONR Marine Meteorology

- XDD fall rates are close to RD-94 (spiral dive)
Conclusions of Peter Black, ONR Marine Meteorology

- RD-94 Ta within 0.5°C; RH after Freq. Restoration

![Graph showing temperature and relative humidity profiles.](image)

- Temp/Ta = Solid
- RH = Dashed
- RD-94 = red
- XDD = blue, black, green
- ‘X’ = NDBC #46026
Conclusions of Peter Black, ONR Marine Meteorology

- Wind directions agree well; ~15° NW vs. 5m buoy

RD-94 = Red
XDD = Blue, Black, Green
“X”=NDBC 46026

Both sondes and aircraft wind dir. differ ~15° vs. 5m buoy winds (anemometer)
Conclusions of Peter Black, ONR Marine Meteorology

- XDD IR-derived SST agreed closely with buoy 46026
**Instrumental Noise Statistics**

**WS std Dev**
- 0.59 m/s

**WD std Dev**
- 6.4°

**Ta std Dev**
- 0.26 °C

**RH std Dev**
- 0.59 %
\[ \frac{dS}{dt} = \frac{1}{C_t} \left( F(t) - S(t) \right) \]

\[ F^* = \frac{C_t}{\Delta T} (S_t - S_{t-1}) + S_t \]
High Definition Sounding System for HS-3 Global Hawk

- NASA DC-8 flight test in 2012 with GH mission in 2013
- Development of UAV sampling strategies and surveillance
High Fast Aircraft can run over the horizon from a slow Sonde? … and the DC-8 is harder for Sondes than the Global Hawk!

**Fall times vs. Altitude**

**Transmission Elevation Angles at the Surface**

**Transmission Range at the Surface**
Imagine a linear box of virtual pillars in the atmosphere, extending from the surface of the ocean up through the eye wall area of the active hurricane. The boundary of each pillar will be delineated by individual dropsonde soundings. We can then estimate both the net flow of moist static energy and the net airflow into/out of each pillar. Since the physical system is never too far away from equilibrium, we can assume that all energy flows must be compensated by exchanges at the air-sea interface; that is, if there is a net sink in enthalpy, the physical laws of conservation of momentum and thermal energy must be obeyed. Aside from thermal heat flow through each column, the second quantity that must be conserved is angular momentum, otherwise known as wind flow into and out of the pillar. We’ll deduce momentum being deposited into the ocean by measuring wind flows in several adjacent virtual pillars. Underwater measurements would be even better.
Questions?

mcb@yesinc.com

Another Navy ONR SBIR!
An Opinion: Muntz, but with care…

If Sondes cost too much, they won’t be used much, so they’ll cost “too much!”

Drop sondes have been a niche technology to date, so much so that they have been badly under-engineered. ONR stepped in to change that…

But then about costs …

Earl “Mad man” Muntz

First, make it work RIGHT! …. Then think about cost reduction.

Costs aren’t about cutting out capacitors and tubes anymore. Cost reduction is largely make it smaller, design-for-manufacture, tooling, and volume.

To date sonde customers have been exceedingly “Penny wise and pound foolish,” haggling over the cost per sonde with no consideration of the system costs of their deployment. The costs are in the system, sondes are already cheap enough, fix the system! And then sonde costs will fall further, as use goes up.
We believe the RD-94 polymer sensor relative humidity data at CIRPAS were frequency-restored internally via Aspen using the method reported in:


The XDD currently uses a similar polymer-type humidity sensor with a 8 second settling time to 63%. The previous graph shows our raw data restored via:

\[
dS/dt = 1/C_t \left( F(t) - S(t) \right) \\
F^* = C_t/\Delta T \left( S[t] - S [t-1] \right) + S [t]
\]

… followed by some rather *ad hoc* smoothing.
Fall speeds for flight two 25 June 2011: at left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 data is in Red; XDD data in Blue, Black and Green.
Observations of air temperature $T_a$ (solid), and relative humidity $RH$ (dashed), Flight two, 25 June 2011. At left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-45 data is in red, XDD data in blue, black and green. X is data from NDBC buoy 46026.
Observations of wind speed WS (solid) and air temperature Ta (dashed), Flight two, 25 June 2011. At left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 data is in Red; XDD data in Blue, Black and Green. X is data from NDBC buoy 46026.
Observations of wind direction WD: at left, linear geopotential height coordinates (GA); at right, log coordinates emphasizing boundary layer detail. Flight two, 25 June 2011. RD94 data is in Red; XDD data in Blue, Black and Green, “X” is data from 5m anemometer atop NDBC buoy 46026.
Flight two, 25 June 2011 observations of infrared-derived SST (solid green), and air temperature, Ta. At left, linear geopotential height coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 Ta is in solid red; XDD Ta is in dashed blue, black and green. X is SST from NDBC buoy 46026.
Intercomparison Flights at Navy CIRPAS in Marina, CA
The Team

- Mark Beaubien, co-PI/Sr. Engineer (Yankee)
- Will Jeffries, co-PI/Chief Engineer (Yankee)
- Todd Allen, Firmware/Electrical (Yankee)
- Eric Griffin, Software (Yankee)
- Lee Harrison, Atmospheric Science (ASRC)
- Al Gasiewski, RF/EE (Univ. of Colorado)
- Peter Black, Meteorology/Data Analysis (NPGS)
CIRPAS Flight Tests June 24-25, 2011

Chief Master Sgt. (Ret.) R.E. Lee with Vaisala RD-94 and AVAPS on Twin Otter
HDSS Data Flow Architecture

PTU+wind+SST Meteorological Sensors

MEASURE / ACQUIRE

40 MHz UHF Telemetry to MDR

HIVE / COMMUNICATE

mySQL Database on Aircraft

STORE

Satcom-Replicated Database

COMMUNICATE

Data Links to Downstream

NHC Forecast Applications

DECIDE / ACT
One sonde had a very interesting flight

The Pseudo-pressure is the pressure which is hydrostatically-consistent from the GPSS altitude, temperature and RH in the sounding.

- Pseudo Pressure vs Pressure (left ordinate)
- 1:1 line
- GPSS vertical velocity (right ordinate)
What we learned from the experiment and the data

1. A research aircraft’s GPSS replicator cannot be presumed to work well enough to initialize the sondes. (The ADD must supply GPSS replication.)

2. We had an unexpected noise problem on the barometric pressure, nearly 2 mB RMS. (Later testing showed this was due to an unfortunate component substitution at build, which was not caught.)

**Design noise floor is 0.1 mB, and we are achieving it.**

3. The attempt to use the “spiral glide” mode to match the fall rate to the RD-94’s was ill-advised for several reasons: it perturbs GPSS estimation of horizontal and vertical winds; it appears to be a major cause of data loss due to variable antenna orientation; and the low fall speeds won’t be tolerable for future missions in any event.

*The fact that even so we came off well against the RD-94 in everything except the boundary layer RH … does not speak well for the RD-94.*