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

"High Reliability Automated High Resolution Upper Air Measurements for Hurricane Observation"

DEPARTMENT OF THE NAVY
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Mission Goals

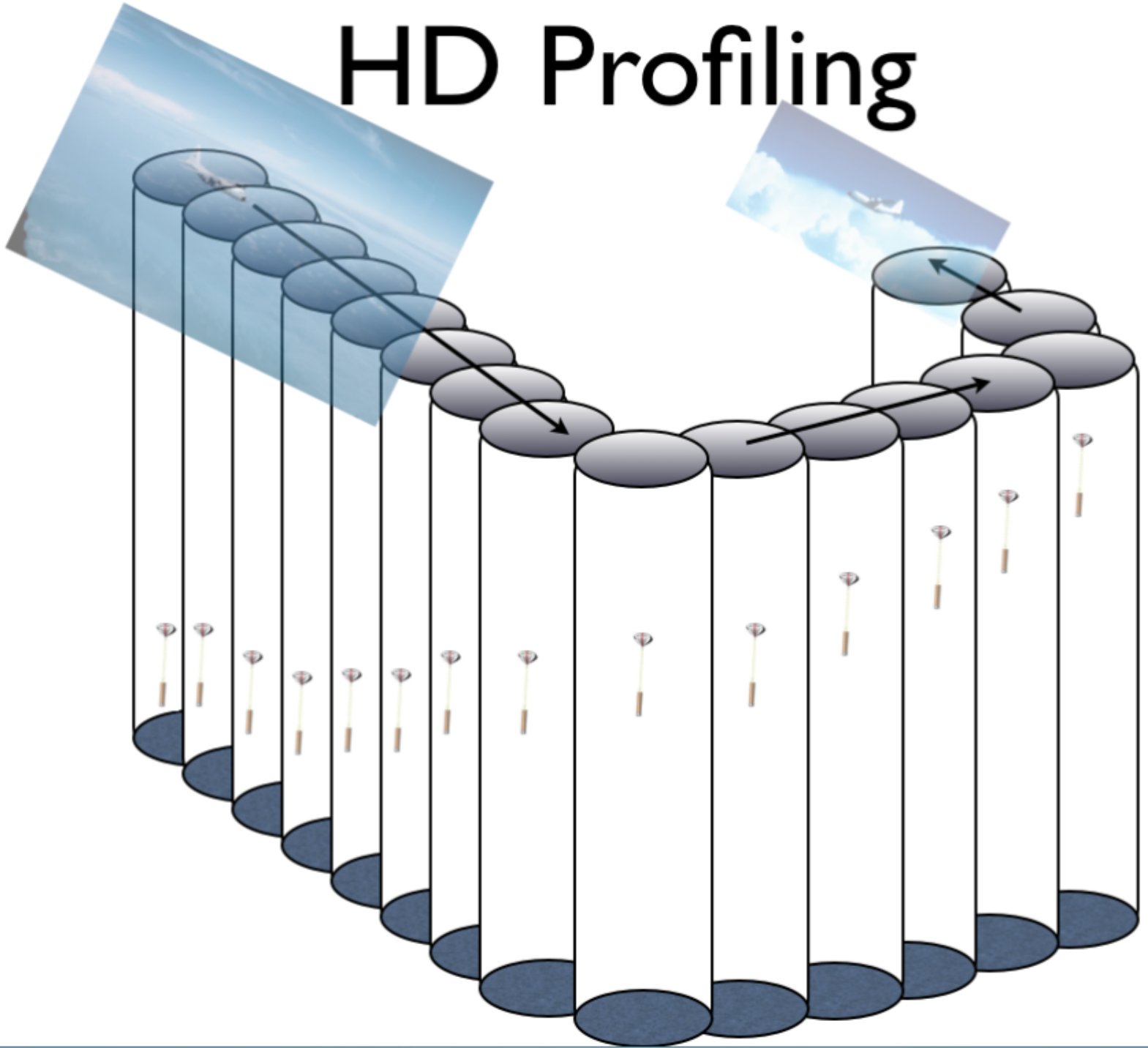
Operational hurricane reconnaissance

- 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

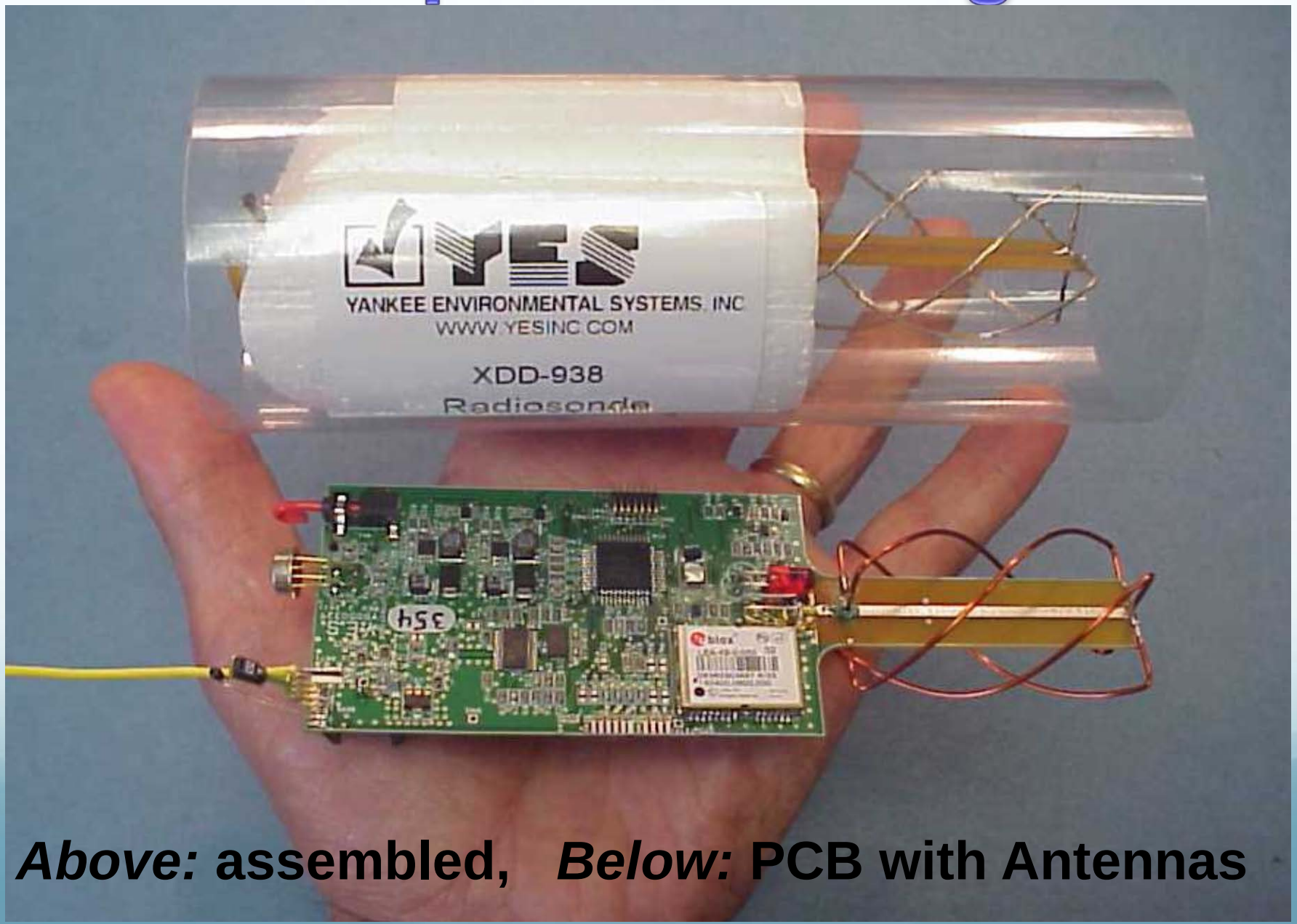
HD Profiling



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

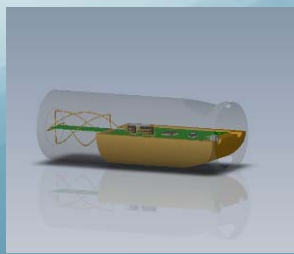


Above: **assembled,** ***Below:*** **PCB with Antennas**

HDSS Component Highlights

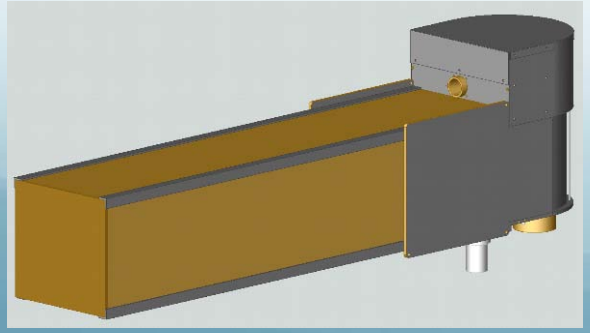
- eXpendable Digital Dropsondes (XDD) measure 4 Hz PTU+Winds, and SST via IR irradiance
- Automated Dropsonde Dispenser (ADD) magazine accommodates up to 48 XDD devices
- An integrated telemetry receiver subsystem **tracks up to 40 XDDs in flight simultaneously** via forward-error-corrected UHF digital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

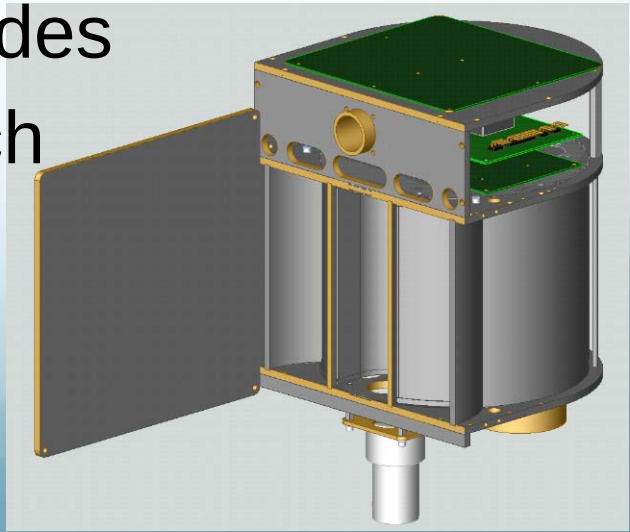
Represents the state-of-the-art for scientific quality, high spatial/temporal resolution soundings in terms of sondes released and simultaneously tracked



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 dropsondes
- 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

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’

We had an ideal marine boundary layer structure …

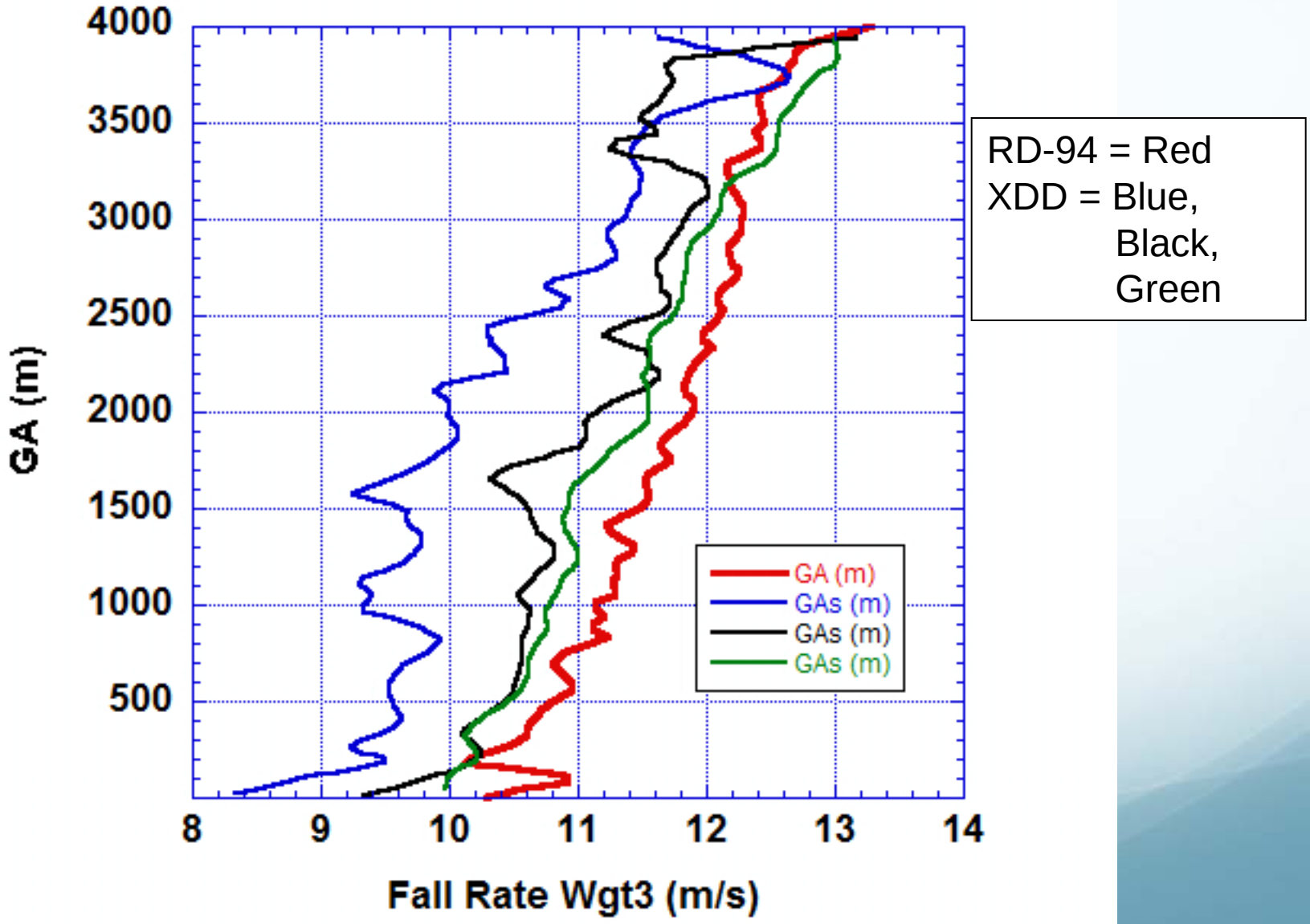
Good Flight Test Results

- 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:

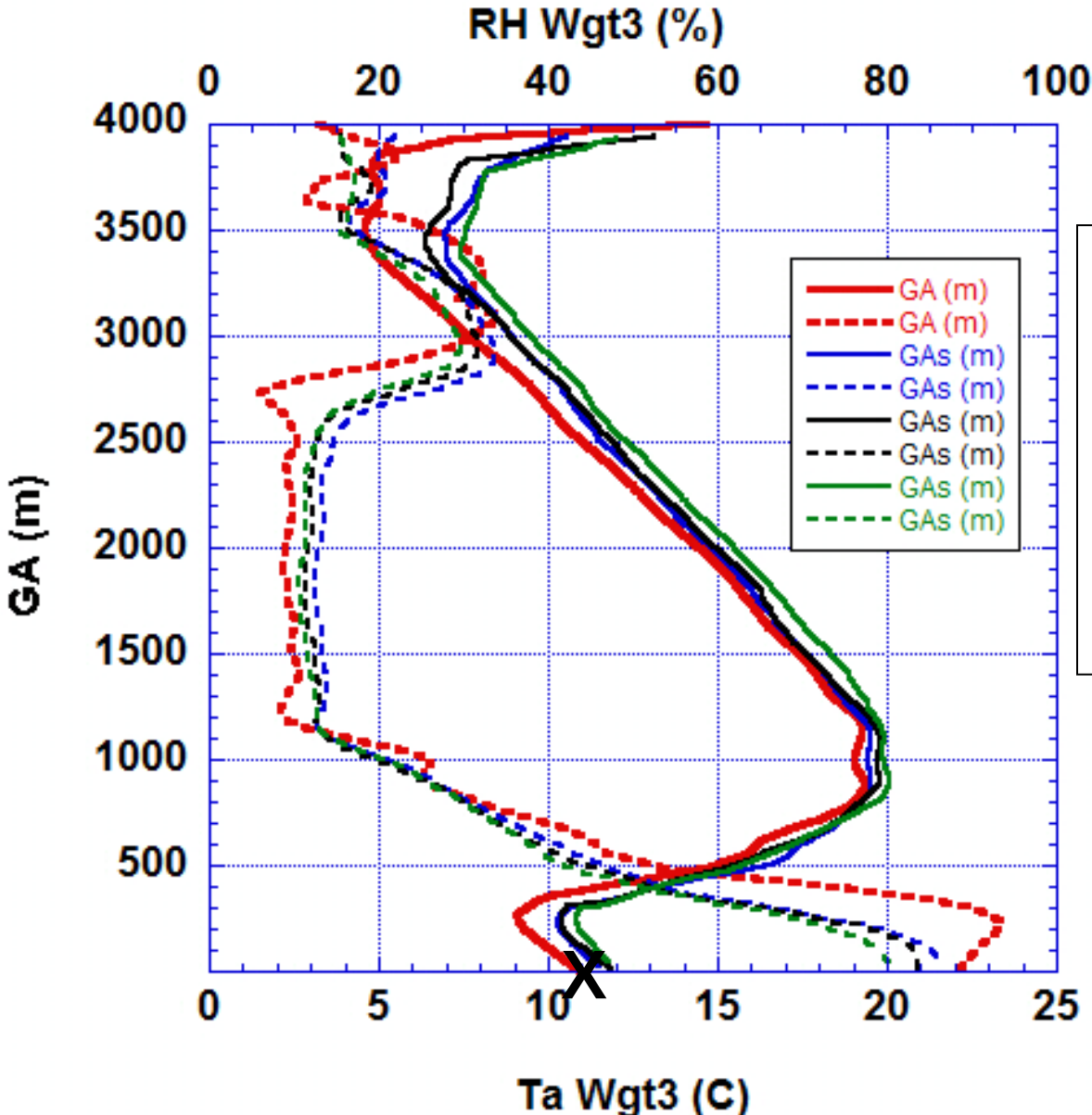
Conclusions of Peter Black, ONR Marine Meteorology

- 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



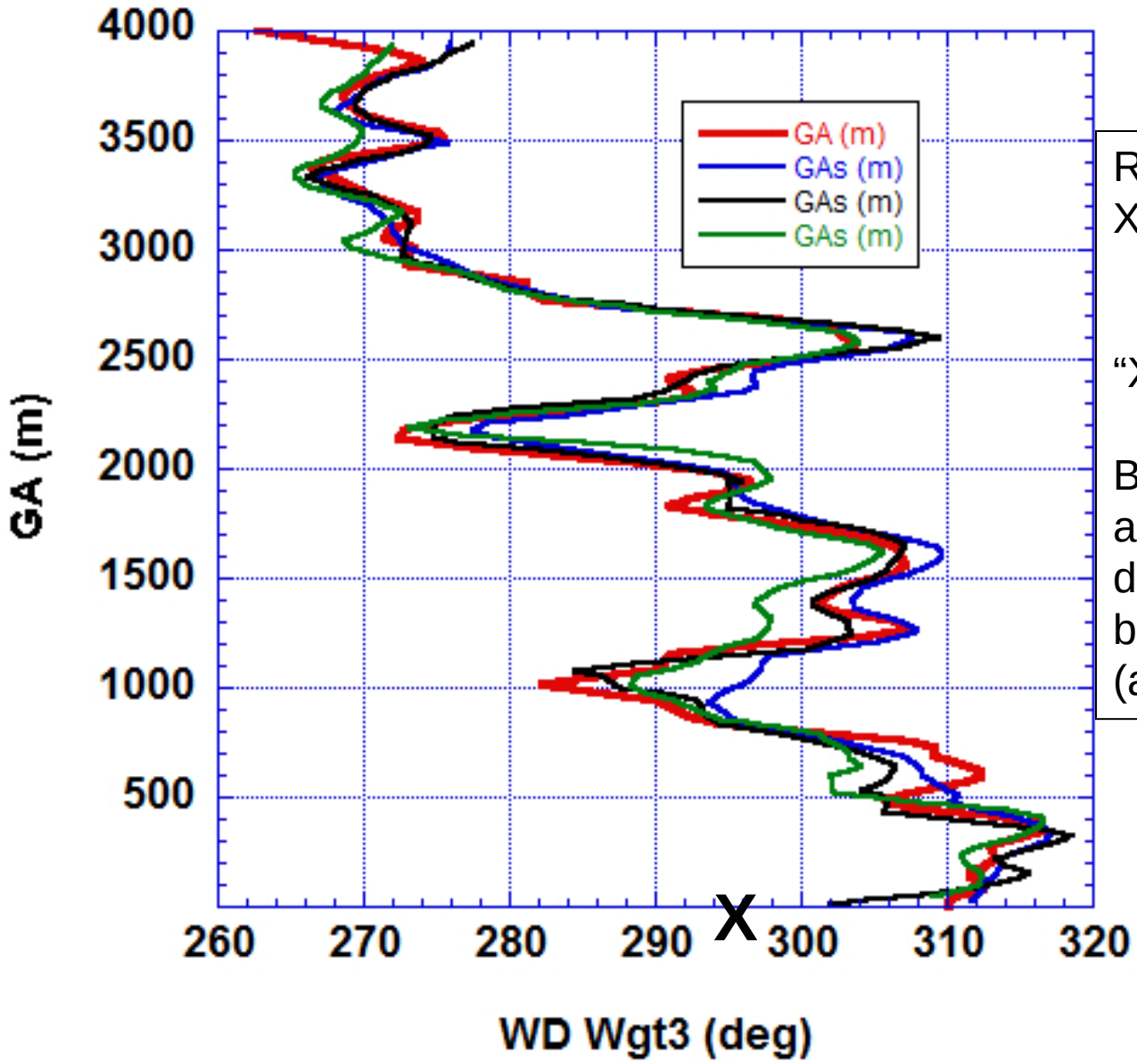
Temp/Ta = Solid
RH = Dashed

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

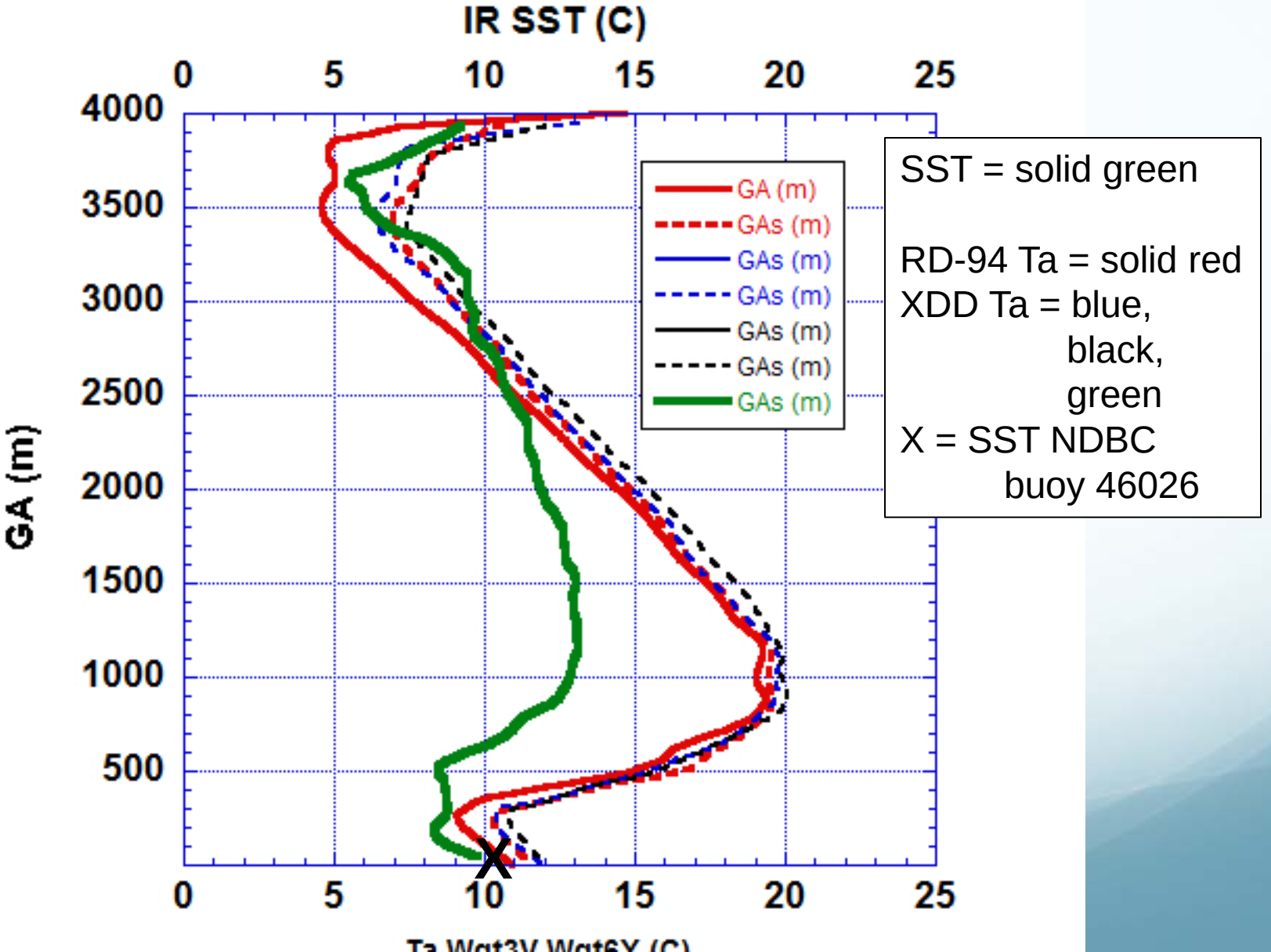


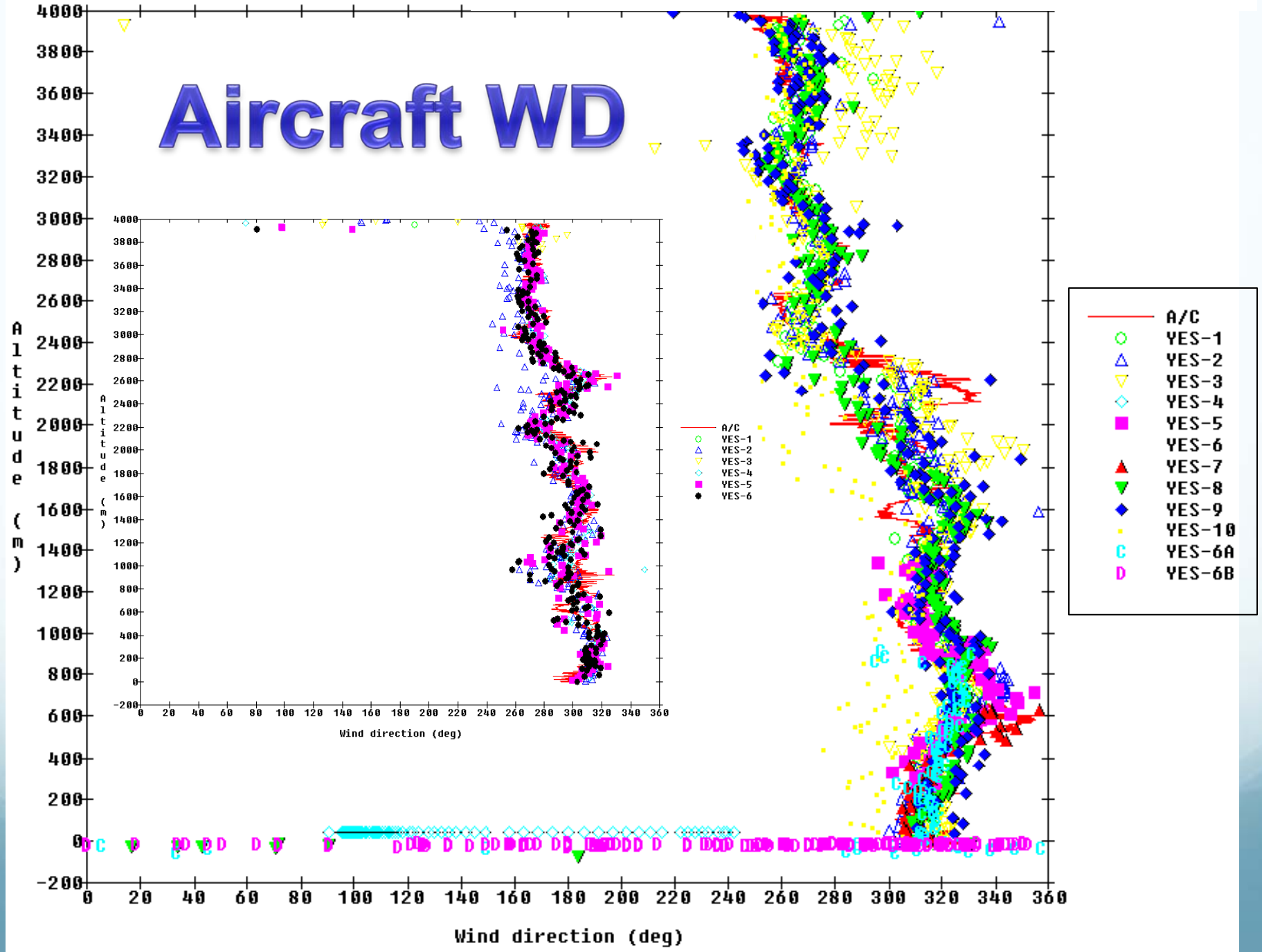
RD-94 = Red
XDD = Blue, Black, Green
"X"=NDBC 46026

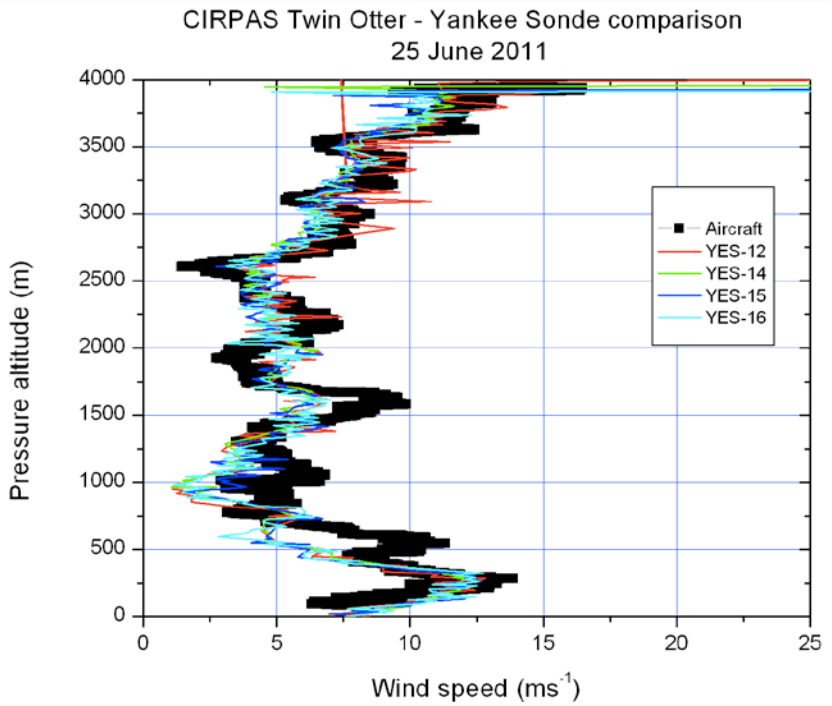
Both sondes and aircraft wind dir. differ ~15° vs. 5m buoy winds (anemometer)

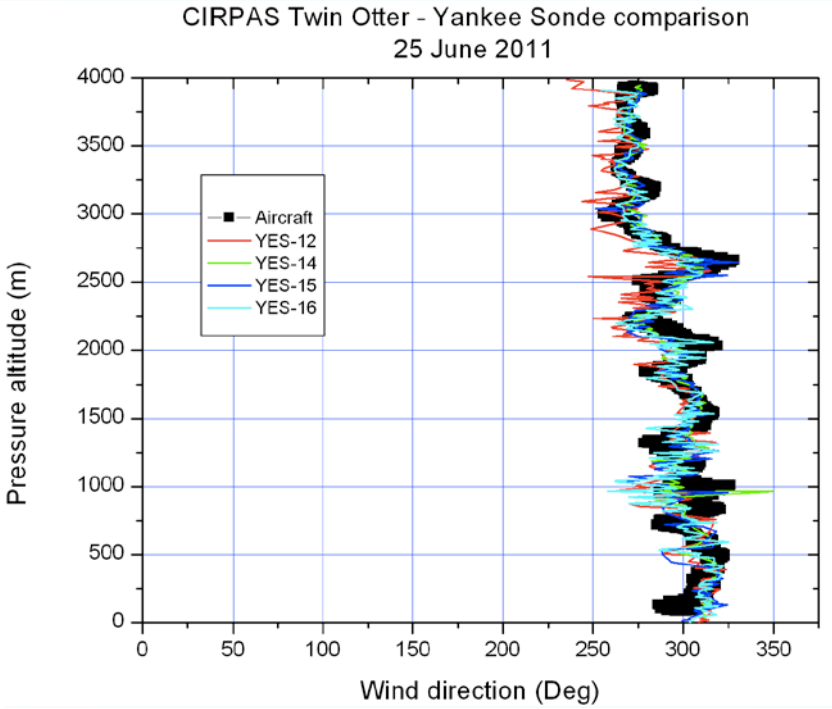
Conclusions of Peter Black, ONR Marine Meteorology

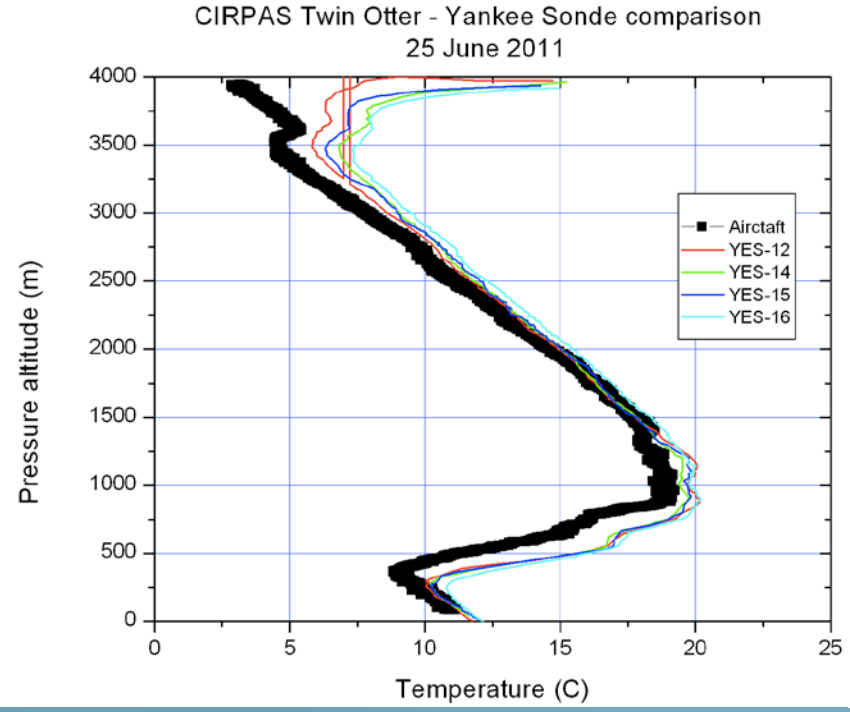
- XDD IR-derived SST agreed closely with buoy 46026

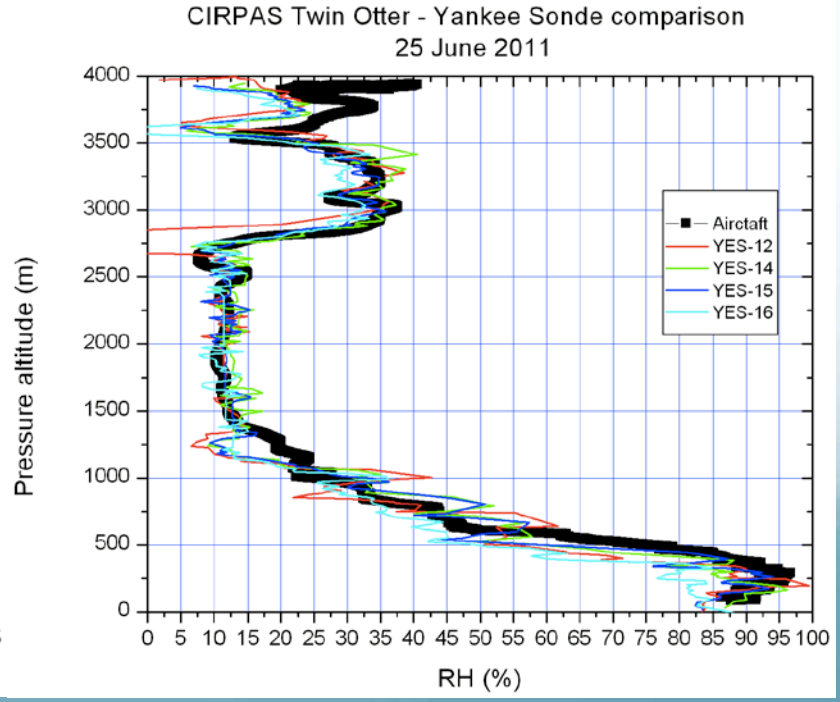



@DROPSONDE_DDD_PROFILE_110624_PQR
Aircraft WD
Altitude (m)
Wind direction (deg)
A/C
YES-1
YES-2
YES-3
YES-4
YES-5
YES-6
YES-7
YES-8
YES-9
YES-10
YES-6A
YES-6B

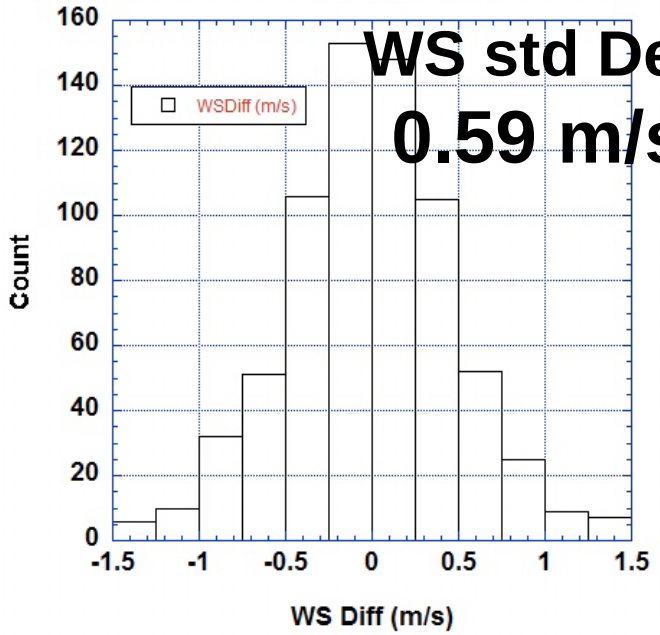

CIRPAS Twin Otter - Yankee Sonde comparison
25 June 2011
Pressure altitude (m)
Wind speed (ms-1)
Aircraft
YES-12
YES-14
YES-15
YES-16


CIRPAS Twin Otter - Yankee Sonde comparison
25 June 2011
Pressure altitude (m)
Wind direction (Deg)
Aircraft
YES-12
YES-14
YES-15
YES-16

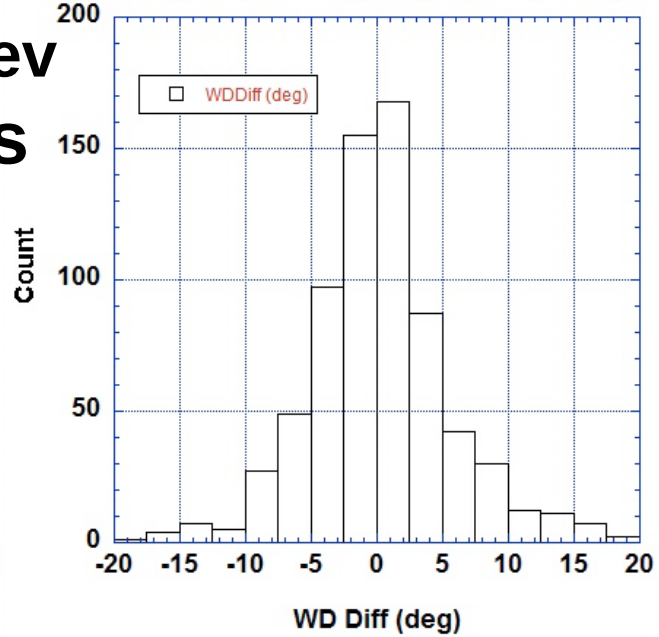

CIRPAS Twin Otter - Yankee Sonde comparison
25 June 2011
Pressure altitude (m)
Temperature (C)
Airctaft
YES-12
YES-14
YES-15
YES-16


CIRPAS Twin Otter - Yankee Sonde comparison
25 June 2011
Pressure altitude (m)
RH (%)
Airctaft
YES-12
YES-14
YES-15
YES-16

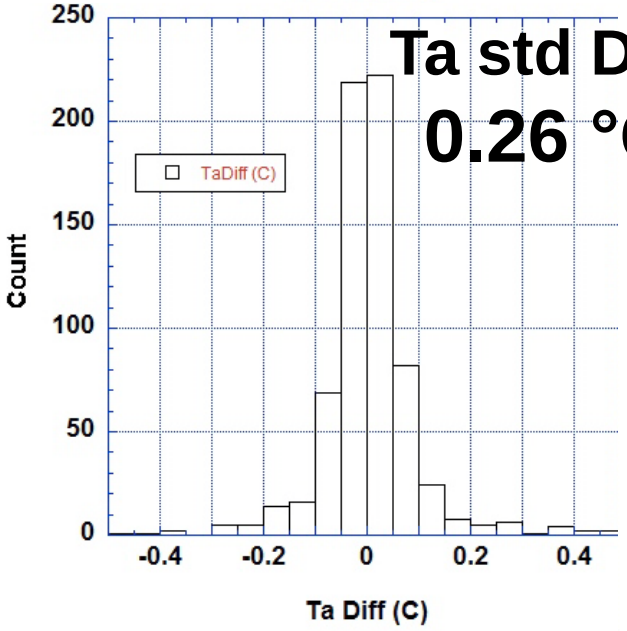
Instrumental Noise Statistics



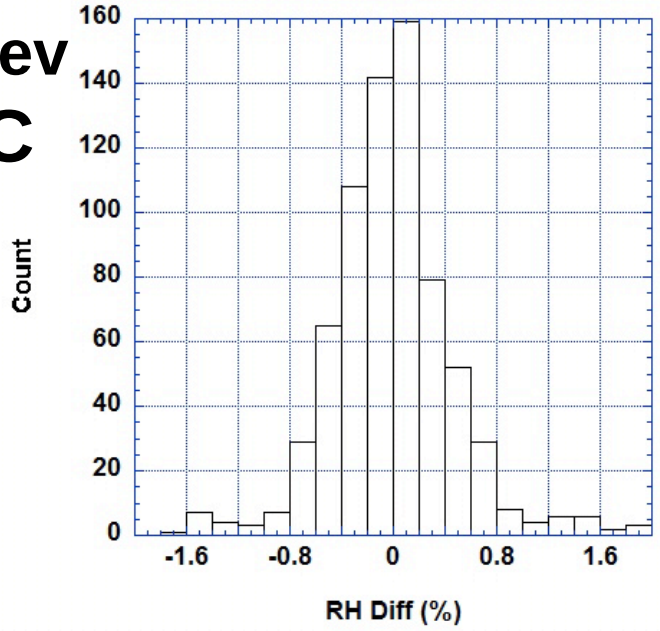
WS std Dev
0.59 m/s



WD std Dev
6.4°

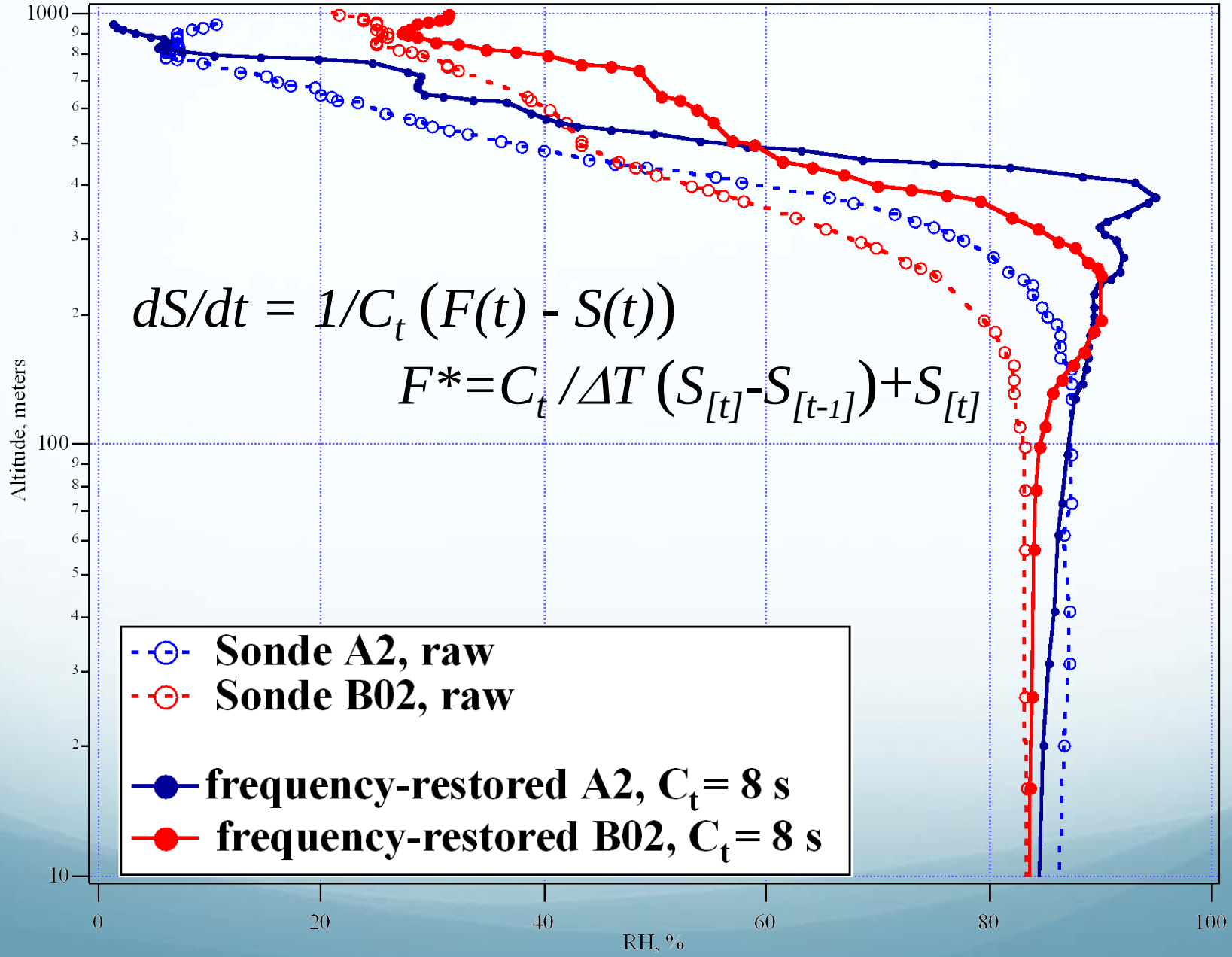


Ta std Dev
0.26 °C



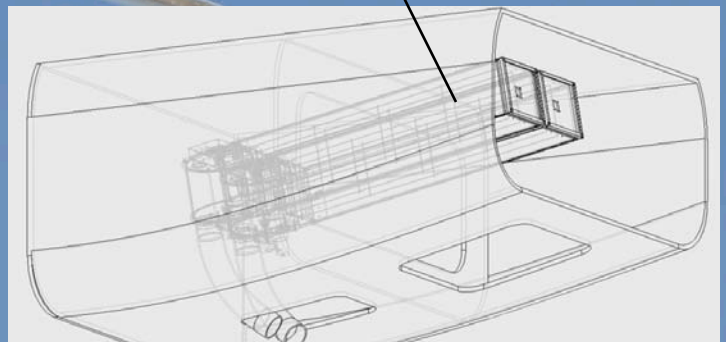
RH std Dev
0.59 %

RH Frequency-Restoration



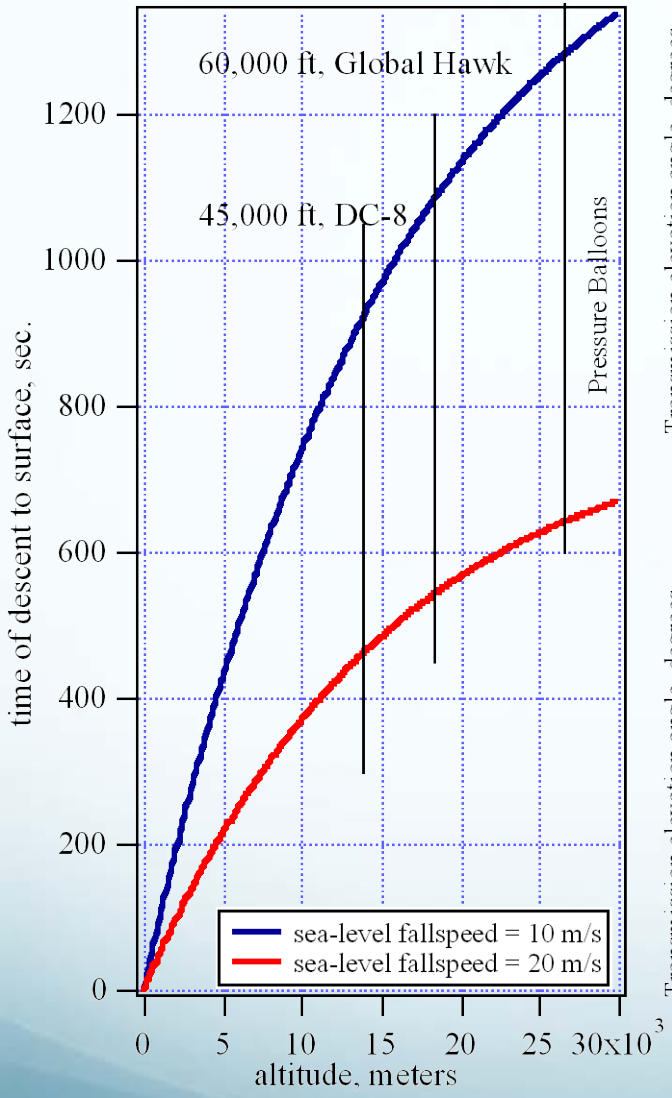
High Definition Sounding System for HS-3 Global Hawk

- NASA DC-8 flight test in 2012 with GH mission in 2013
- Development of UAV sampling strategies and surveillance

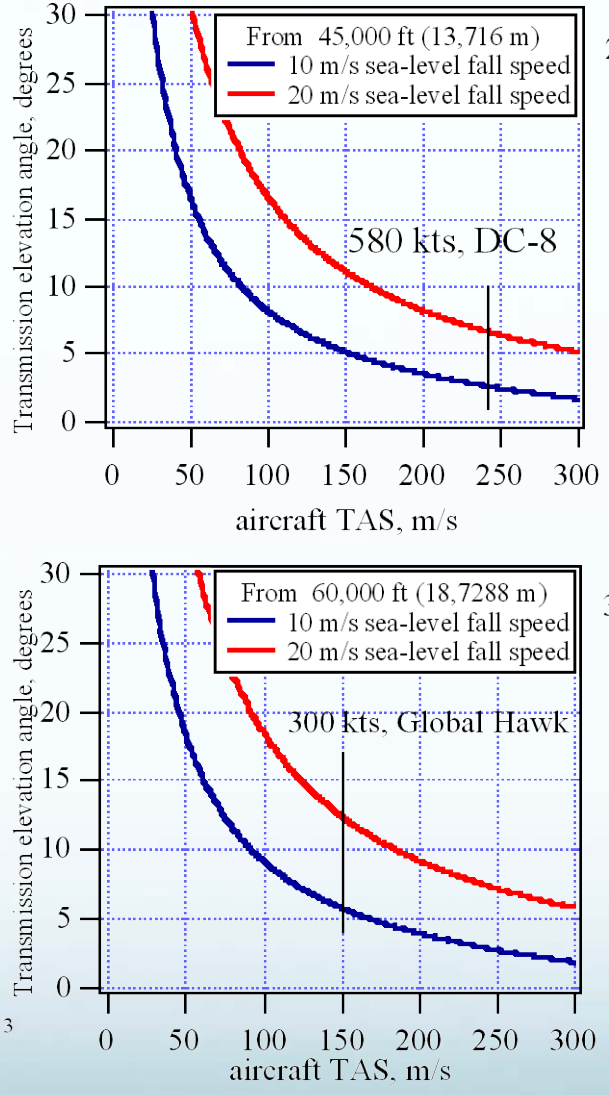


High Fast Aircraft can run over the horizon from a slow Sonde?

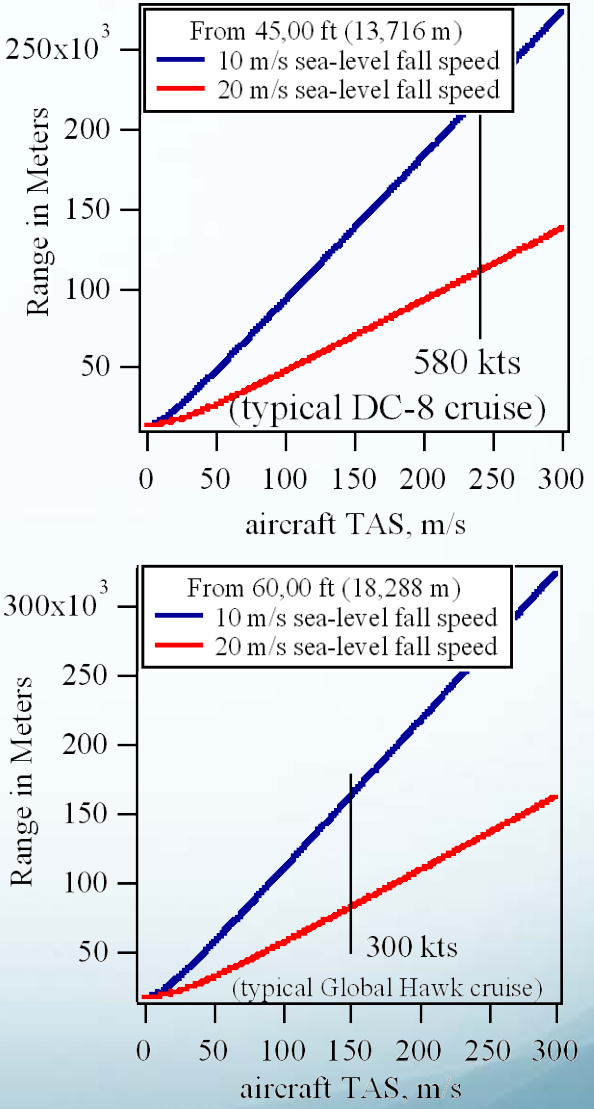
… and the DC-8 is harder for Sondes than the Global Hawk!



Fall times vs. Altitude



Transmission Elevation Angles at the Surface

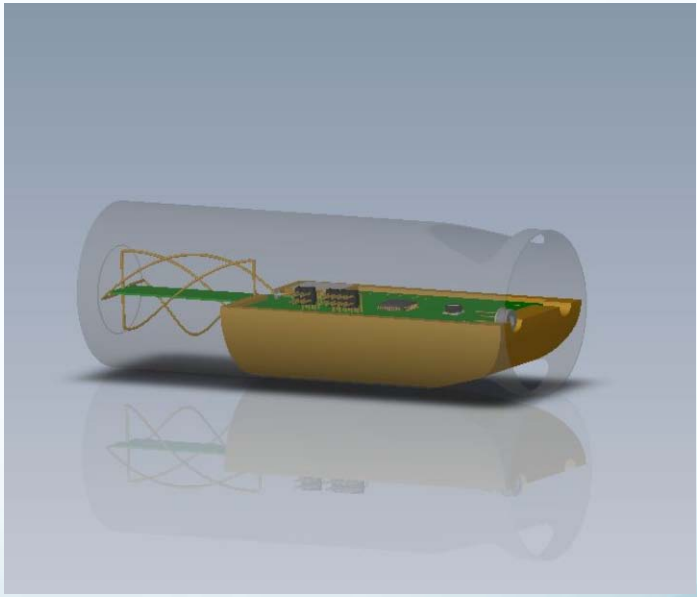


Transmission Range at the Surface

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 !

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An Opinion: Muntz, but with care…

Earl "Mad man" Muntz

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 …

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.

RH Measurement Agreement

We believe the RD-94 polymer sensor relative humidity data at CIRPAS were frequency-restored internally via Aspen using the method reported in:

GÉ Verver, M. Fujiwara, P. Dolmans, C. Becker, P.L Fortuin L. Milosevitch, (2006) *Performance of the Vaisala RS80A/H and RS90 Humicap Sensors and the Meteolabor "Snow White" Chilled-Mirror Hygrometer in Paramaribo, Suriname* J. Atmos. Oceanic Tech. **23**, 1506–1517.

Miloshevich, L. M., H. Vömel, A. Paukkunen, A. J. Heymsfield, and S. J. Oltmans, 2001: *Characterization and correction of relative humidity measurements from Vaisala RS80-A radiosondes at cold temperatures*. J. Atmos. Oceanic Tech.,**18**, 135–156.

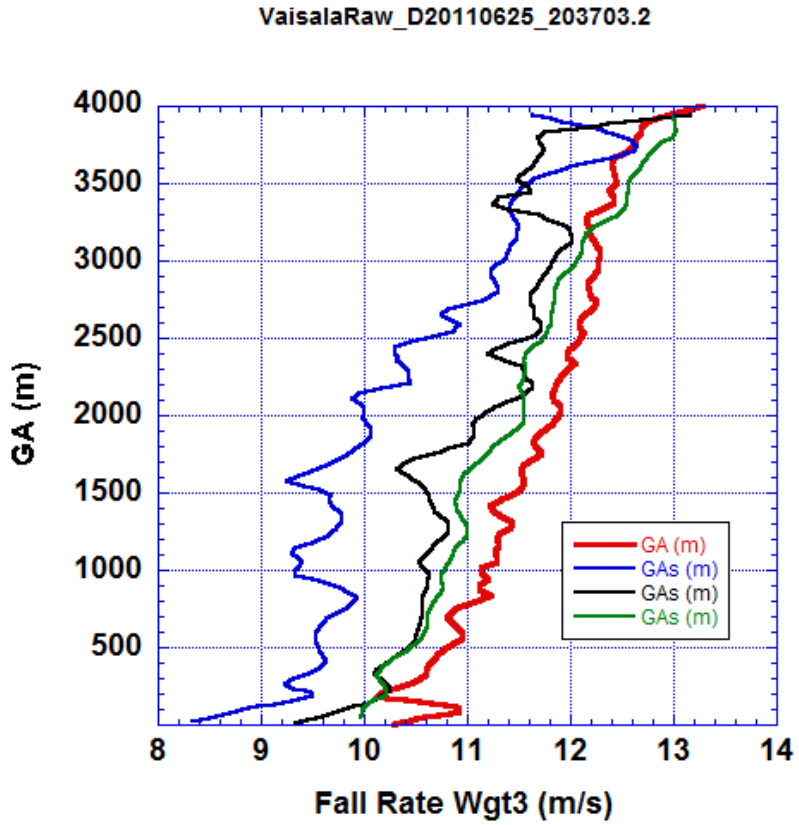
The XDD currently uses a similar polymer-type humidity sensor with a 8 second settling time to 63%. The previous graph shows our raw data restored via:

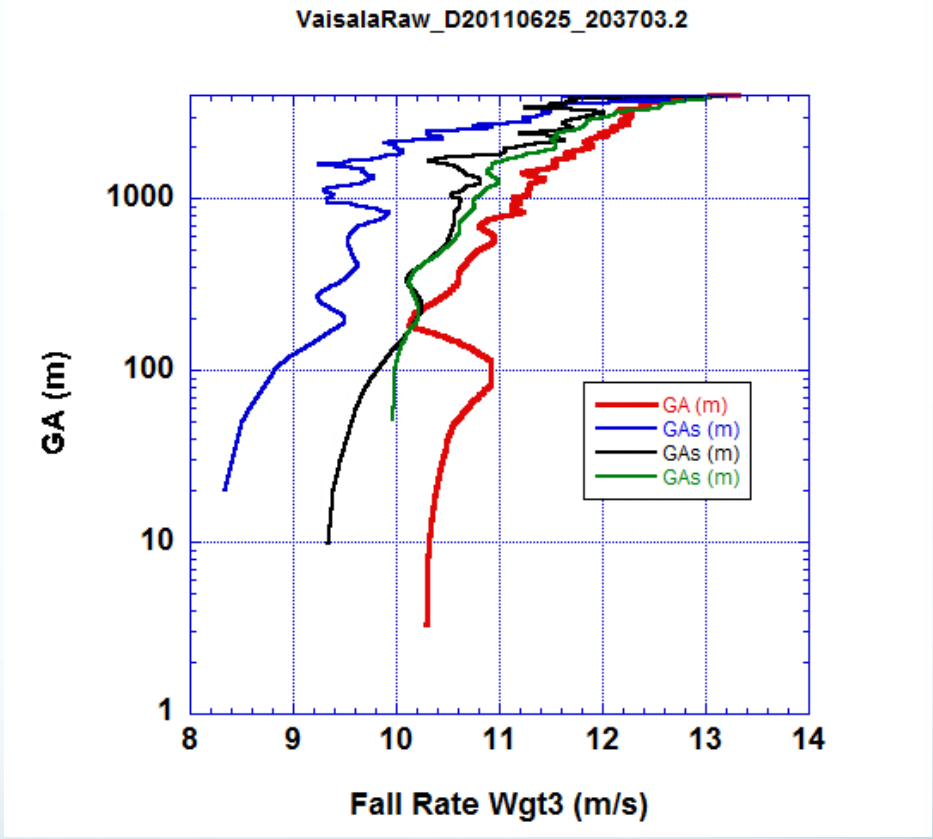
$$dS/dt = 1/C_t \left(F(t) - S(t)\right)$$

$$F^* = C_t^{\cdot}/\Delta T \left(S_{[t]} - S_{[t-1]}\right) + S_{[t]}$$

… followed by some rather *ad hoc* smoothing.

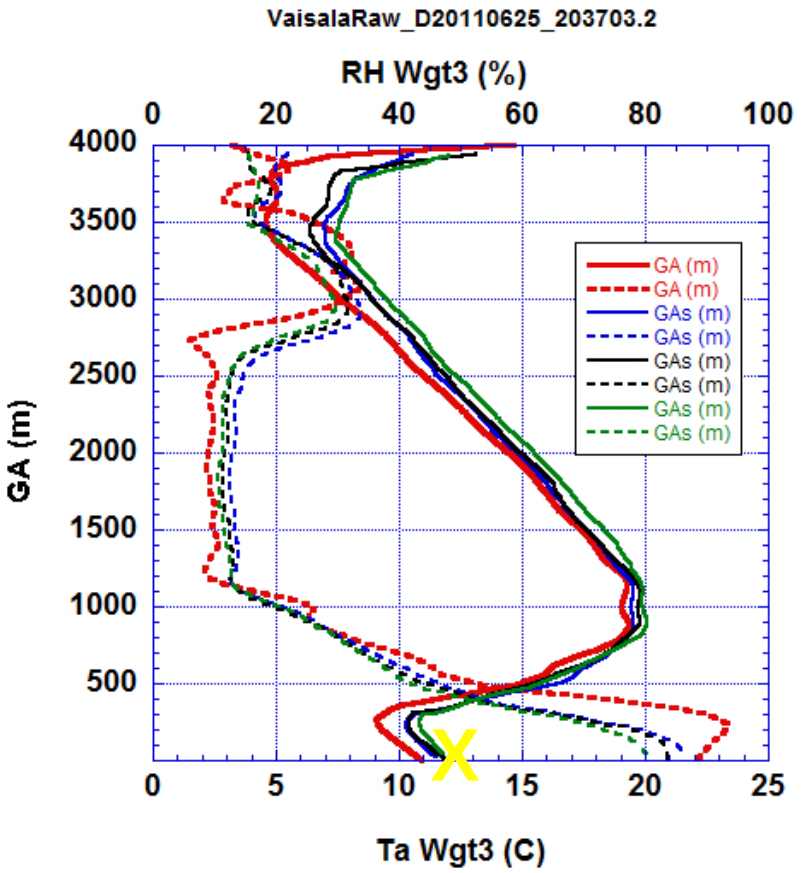
Dropsonde Fall Velocity

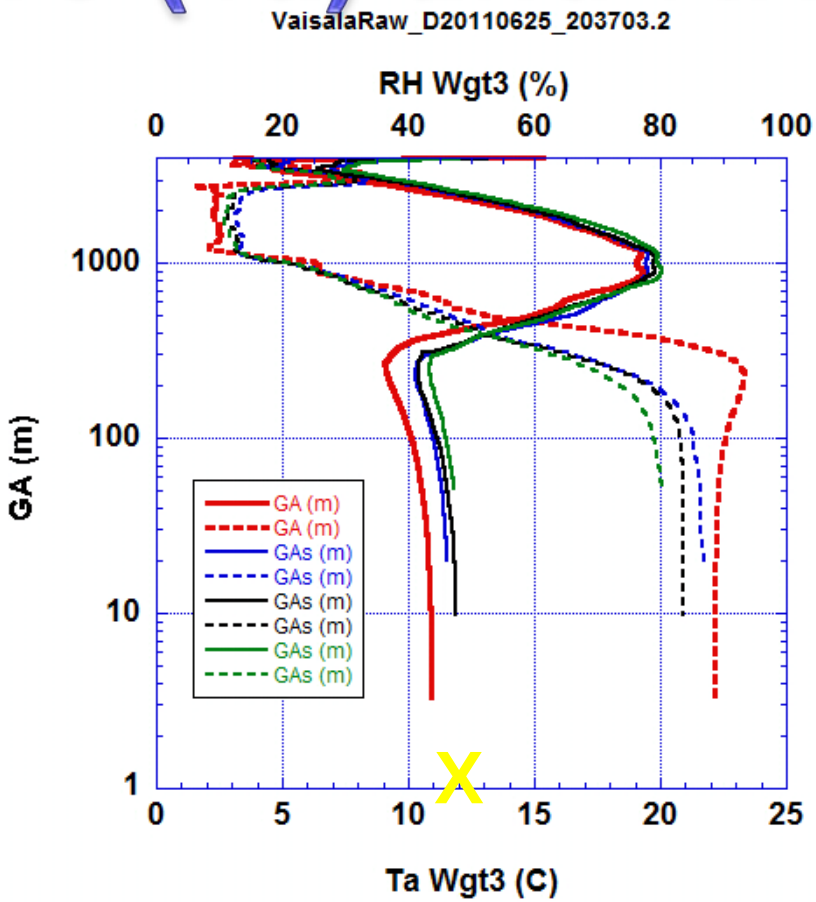




Fall speeds for flight two 25 June 2011: at left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 data is in Red; XDD data in Blue, Black and Green.

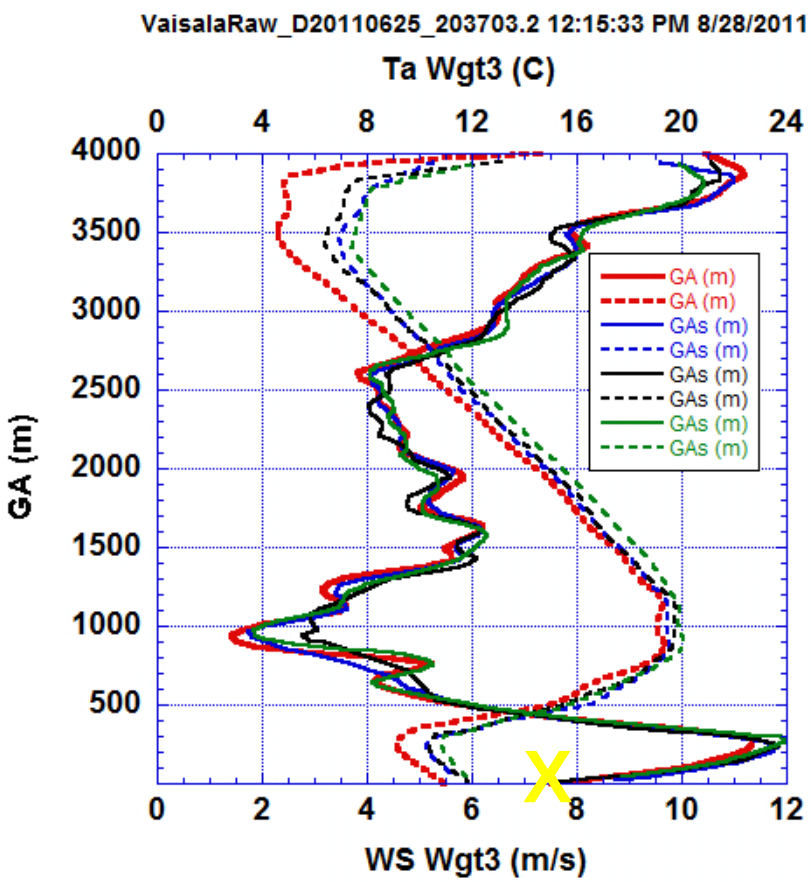
Air Temperature (Ta) and RH

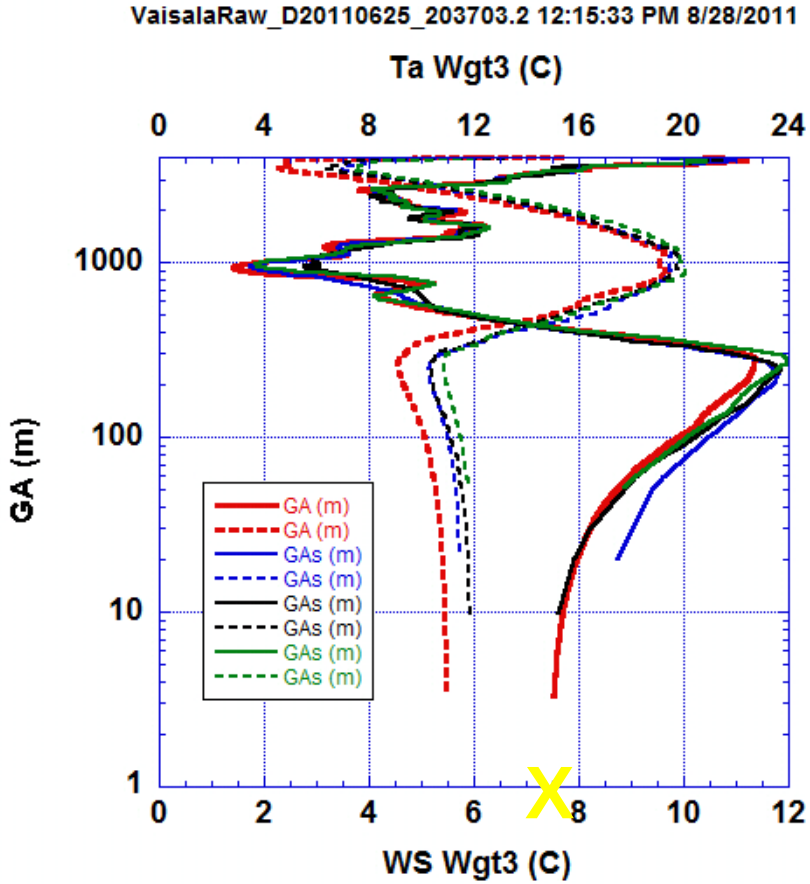




Observations of air temperature Ta (solid), and relative humidity RH (dashed), Flight two, 25 June 2011. At left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-45 data is in red, XDD data in blue, black and green. X is data from NDBC buoy 46026.

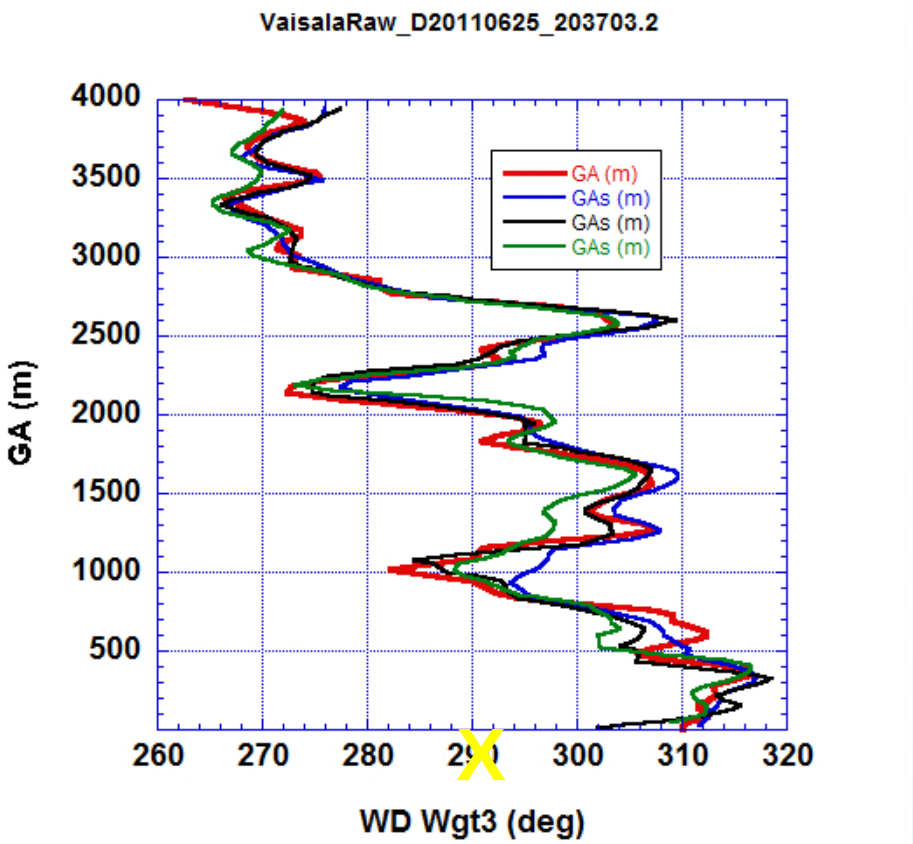
Wind Speed and Air Temp (Ta)

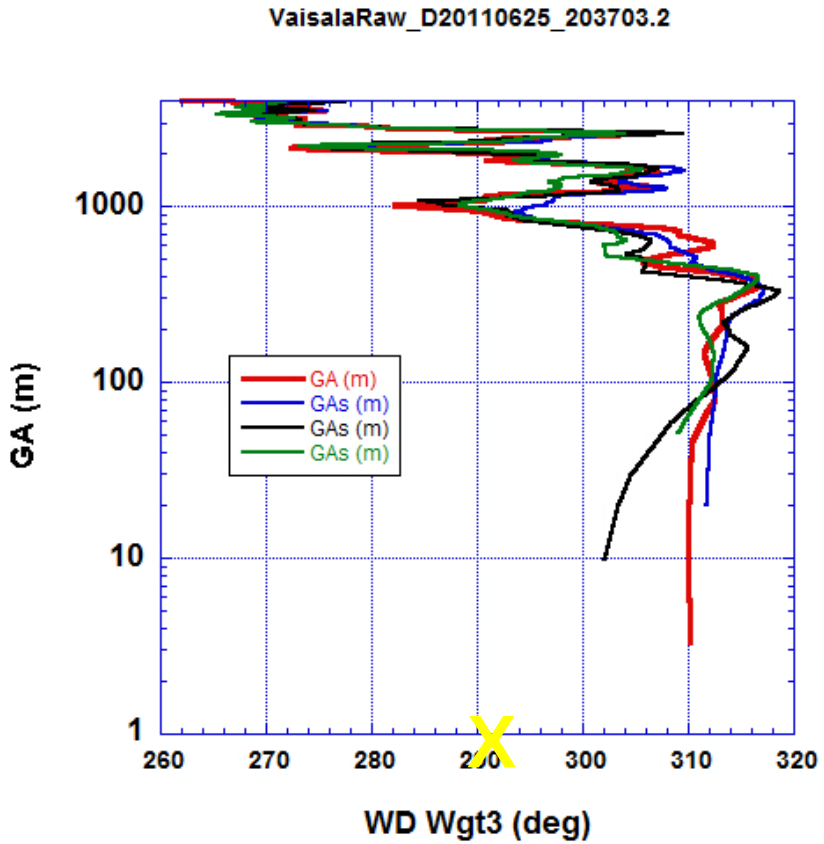




Observations of wind speed WS (solid) and air temperature Ta (dashed), Flight two, 25 June 2011. At left, linear geopotential height (GA) coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 data is in Red; XDD data in Blue, Black and Green. X is data from NDBC buoy 46026.

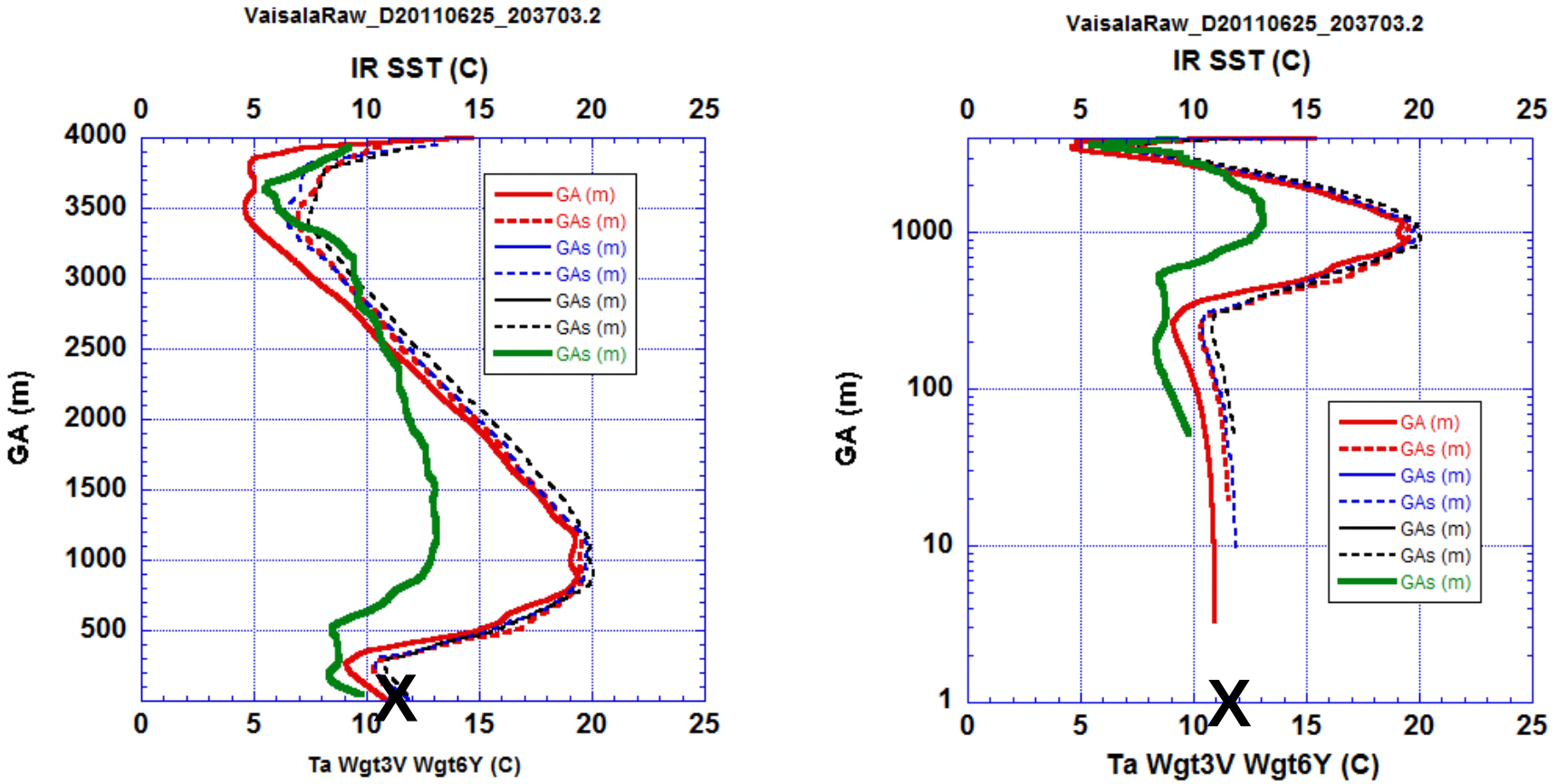
Wind Dir vs. Geo-Altitude (GA)





Observations of wind direction WD: at left, linear geopotential height coordinates (GA); at right, log coordinates emphasizing boundary layer detail. Flight two, 25June 2011. RD94 data is in Red; XDD data in Blue, Black and Green, “X” is data from 5m anemometer atop NDBC buoy 46026.

Buoy, IR-derived SST, and Ta

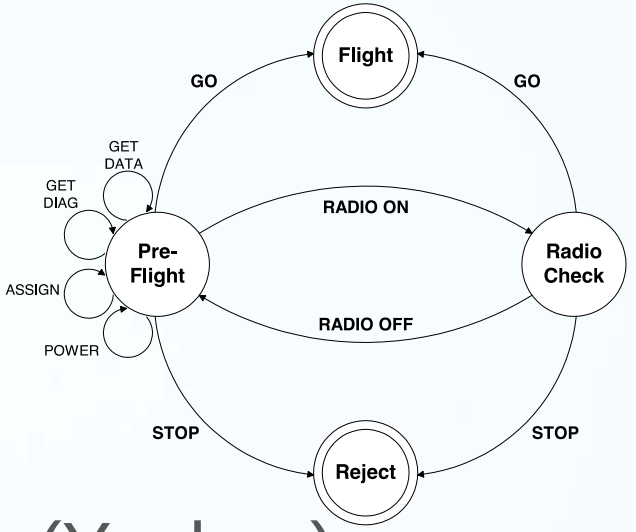


Flight two, 25 June 2011 observations of infrared-derived SST (solid green), and air temperature, Ta. At left, linear geopotential height coordinates; at right, log coordinates emphasizing boundary layer detail. RD-94 Ta is in solid red; XDD Ta is in dashed blue, black and green. X is SST from NDBC buoy 46026.

Intercomparison Flights at Navy CIRPAS in Marina, CA

Greg Cooper Robt. E. Lee Robert Bluth
Lee Harrison Peter Black Mark Beaubien Roy Woods

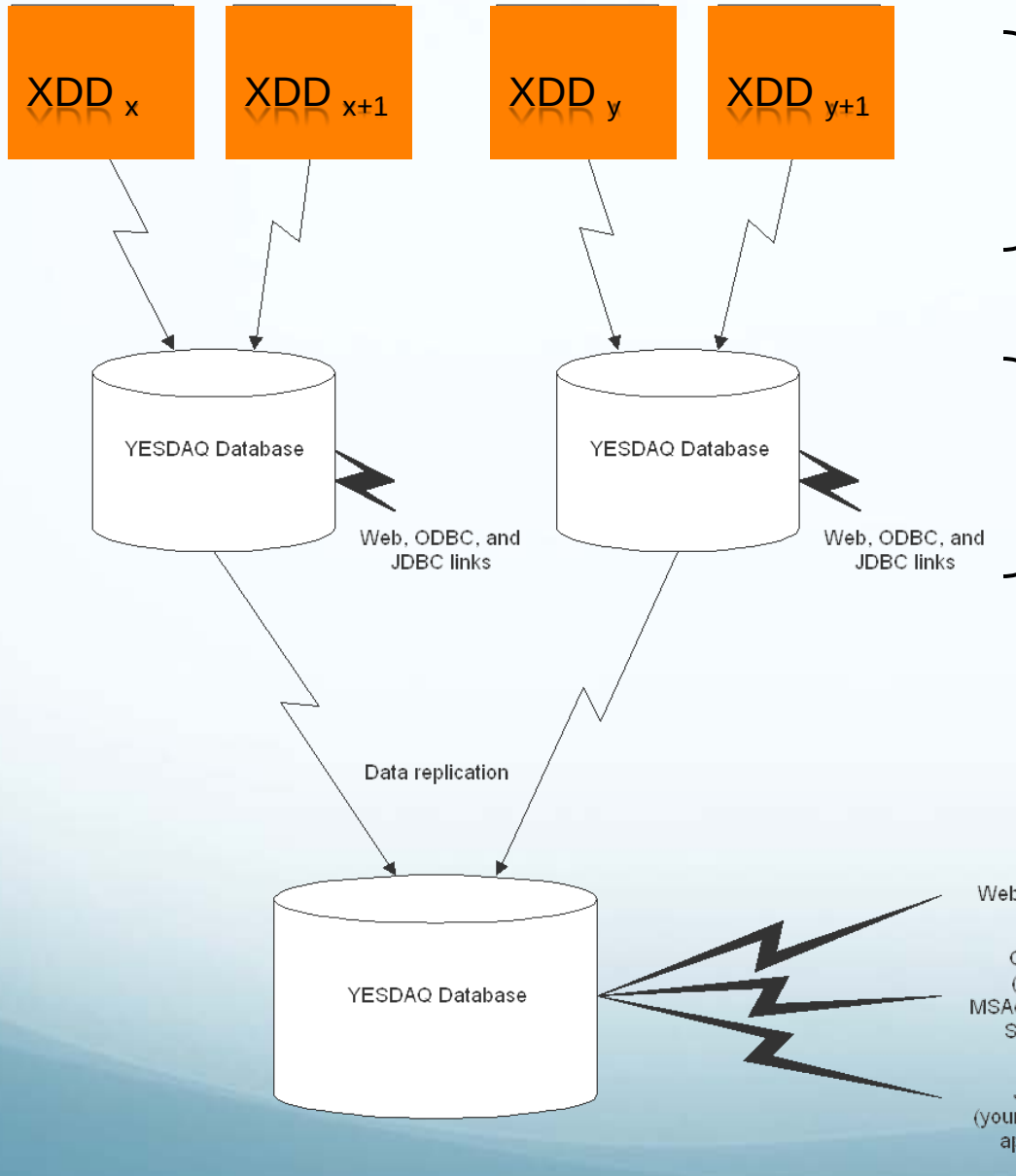
The Team



- 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)

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

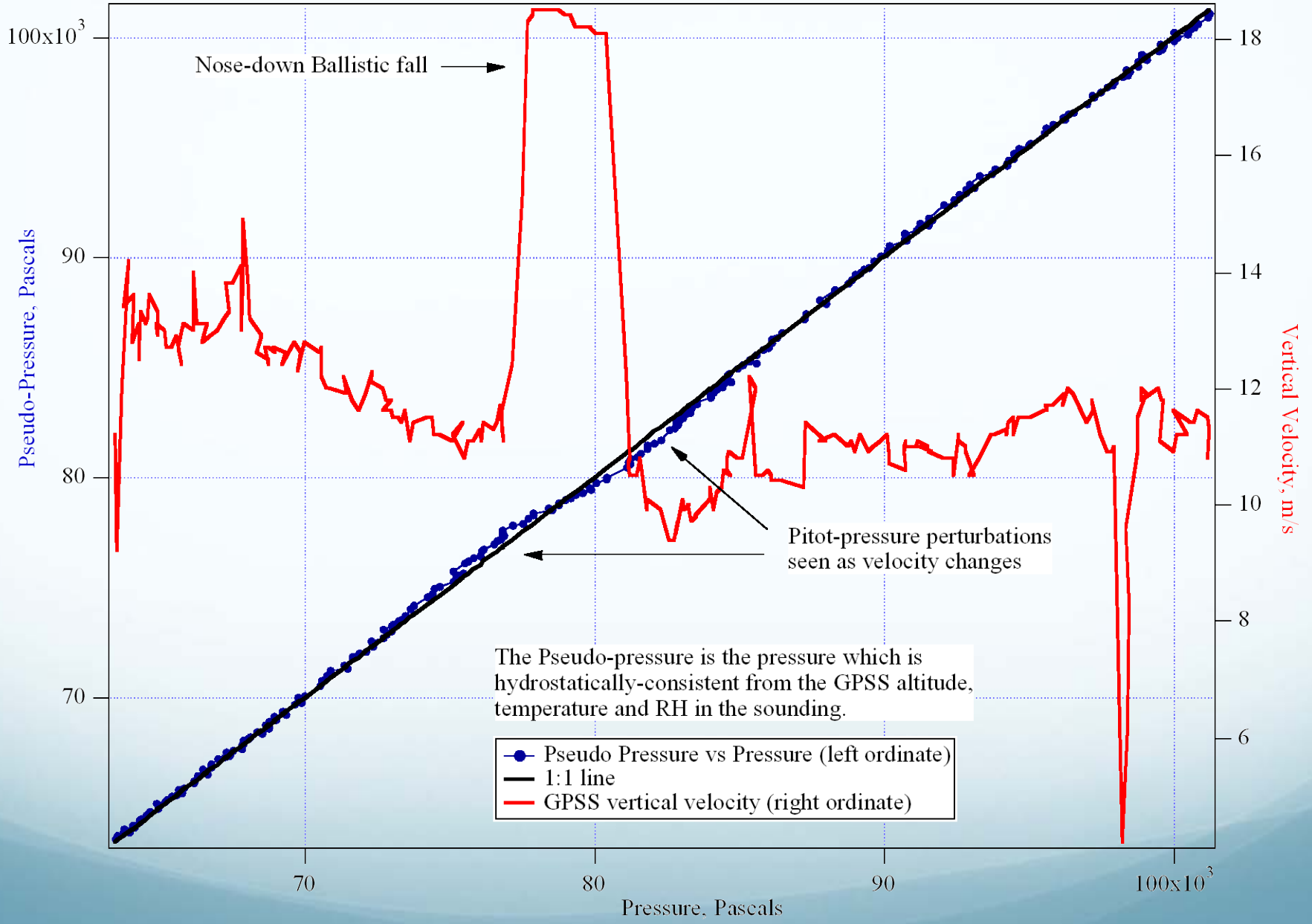
40 MHz UHF Telemetry to MDR
HIVE / COMMUNICATE

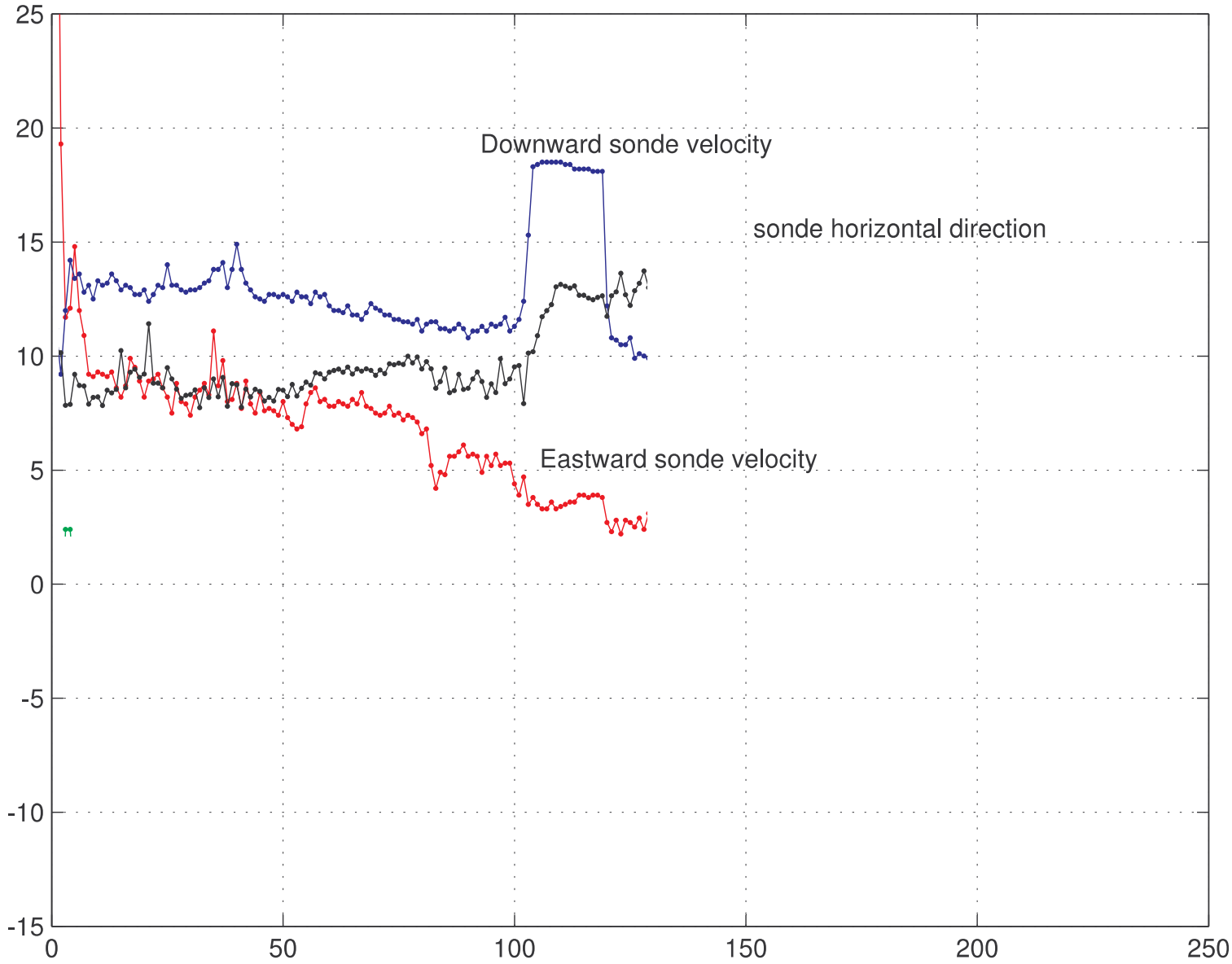
mySQL Database on Aircraft
STORE

Satcom-Replicated Database
COMMUNICATE

Data Links to Downstream NHC Forecast Applications
DECIDE / ACT

One sonde had a very interesting flight




Downward sonde velocity
sonde horizontal direction
Eastward sonde velocity
25
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250

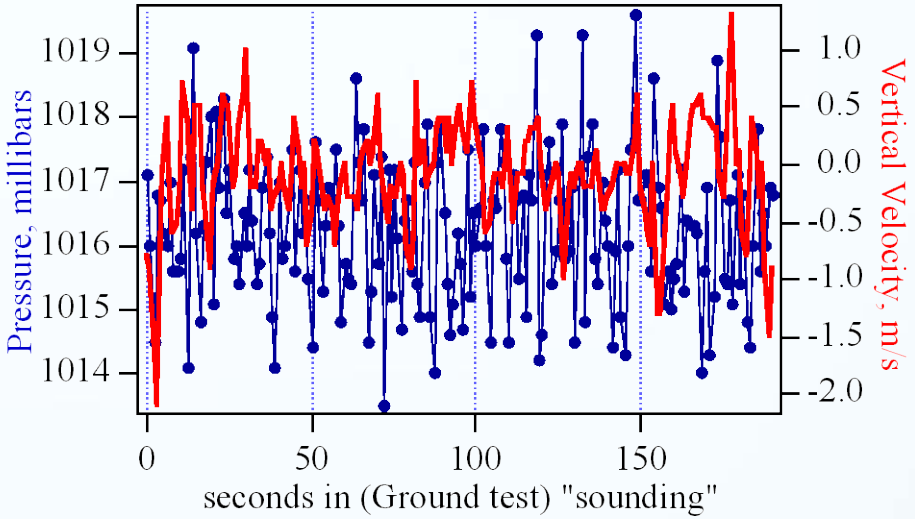
What we learned from the experiment and the data

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.

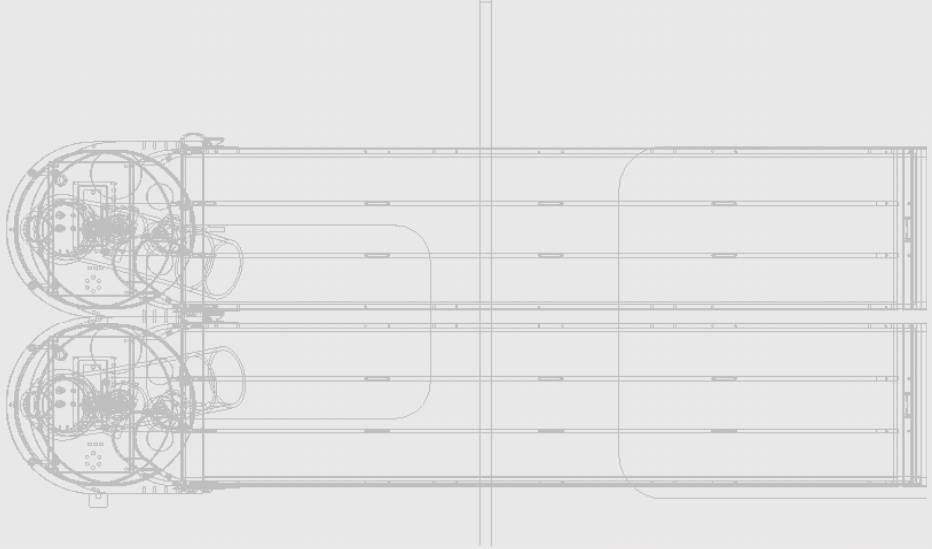
(Later testing showed this was due to an unfortunate component substitution at build, which was not caught.)

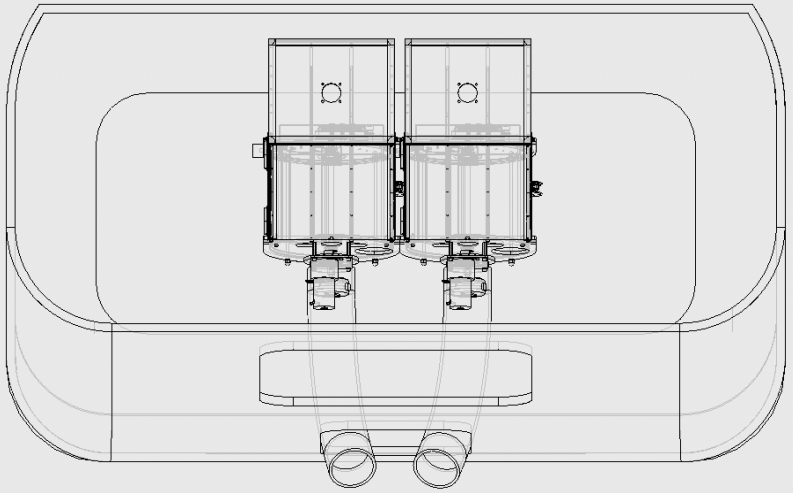
Design noise floor is 0.1 mB, and we are achieving it.

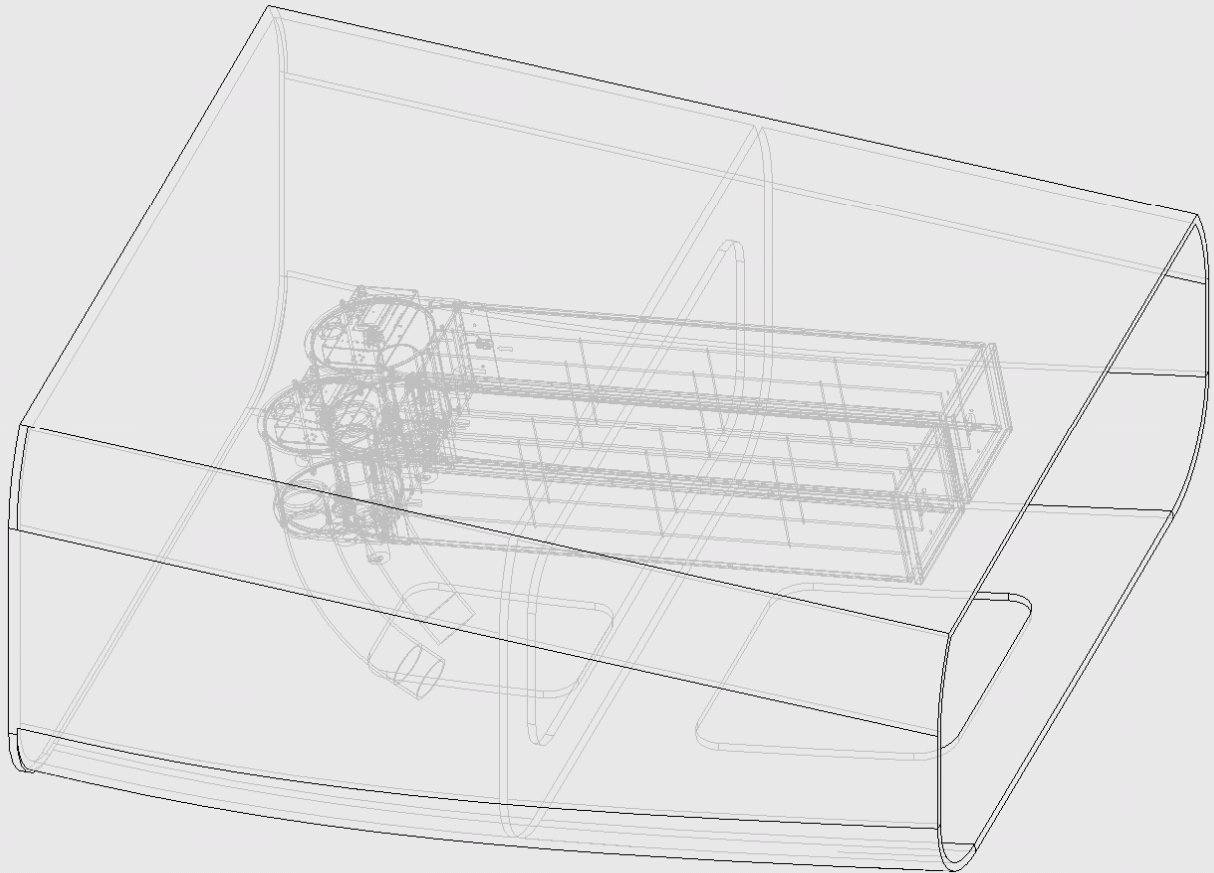


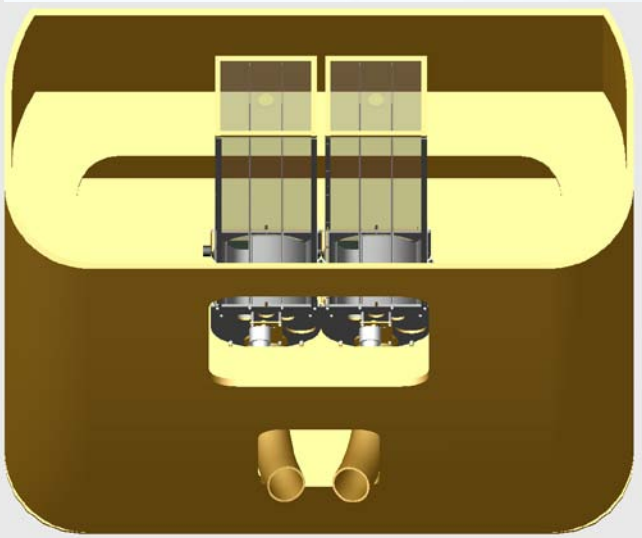
3. The attempt to use the "spiral glide" mode to match the fall rate to the RD-94's was ill-advised for several reasons: it perturbs GPSS estimation of horizontal and vertical winds; it appears to be a major cause of data loss due to variable antenna orientation; and the low fall speeds won't be tolerable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

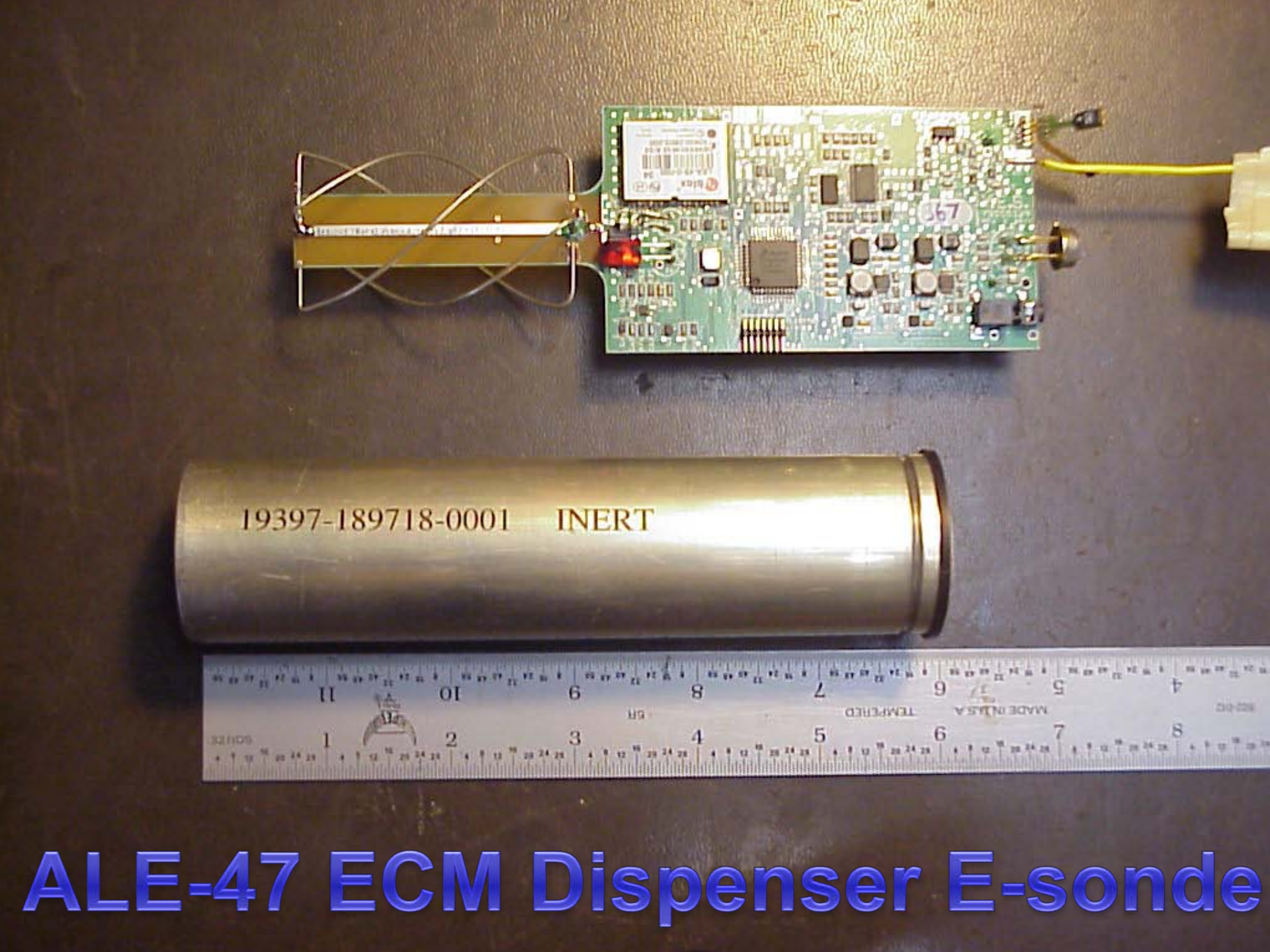
The fact that even so we came off well against the RD-94 in everything except the boundary layer RH … does not speak well for the RD-94.










19397-189718-0001 INERT
ALE-47 ECM Dispenser E-sonde