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High Definition Sounding System (HDSS) for airborne atmospheric profiling in Tropical Cyclones (TCs) and severe weather

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HDSS/ XDD Validation Experiments

The HDSS deploys the eXpendable Digital Dropsonde (XDD), which measures atmospheric profiles of Pressure, Temperature, hUmidity (PTU), horizontal and vertical winds as well as Sea Surface Temperature (SST) via a new mini-InfraRed (IR) sensor. The XDD was developed for measurements in the Tropical Cyclone (TC) inner core and environment as well as in other high-impact weather events. This paper discusses validation aboard a Navy Twin Otter from 4 km, the NASA DC-8 from 12 km, and a NASA WB-57 from 18 km.

Observations from Twin Otter spiral descents from 4 km to 30 m altitude on two successive days off the California coast over offshore buoys were compared to PTU, winds and IR SST measurements from 10 XDDs deployed simultaneously. The XDD profiles showed excellent agreement with those from the spirals as well as with 14 coincident NCAR/Vaisala RD94 dropsonde PTU and wind profiles. Differences between successive XDD and RD-94 profiles due to true meteorological variability were on the same order as profile differences between the spirals, XDDs and RD-94s. Buoy SST and surface winds were within 0.5C and 1.5 m/s of the XDD measurements.

The DC-8 flight intercompared six XDDs against each other to the east of ex-TC Cosme, south-west of Cabo San Lucas, Mexico. Good agreement was found between successive PTU and wind profiles as well as SST over a range of 10C. SSTs and surface winds again agreed well with two SVP drifting buoys, satellite-derived IR SSTs and satellite scatterometer-derived winds. The WB-57 flights intercompared XDDs with NWS radiosonde profiles from Brownsville and Corpus Christi, employing two XDD fall rates. The fast-falls showed superior agreement of PTU and winds..

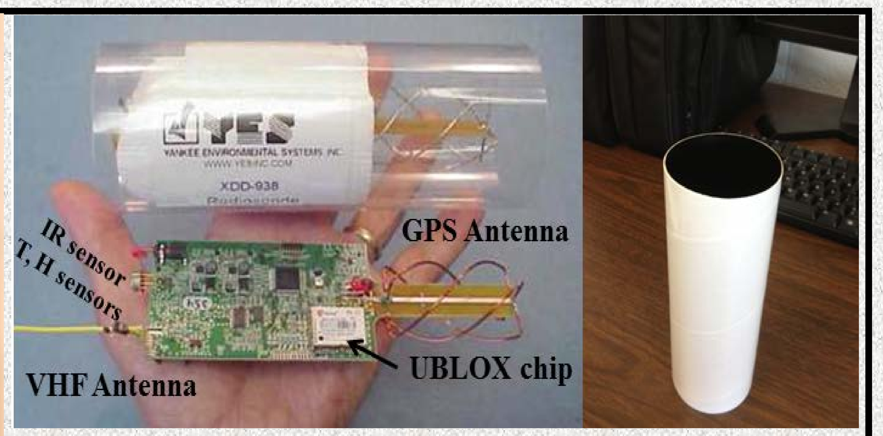
Twin Otter and Science Team

WB-57 and Flight Crews

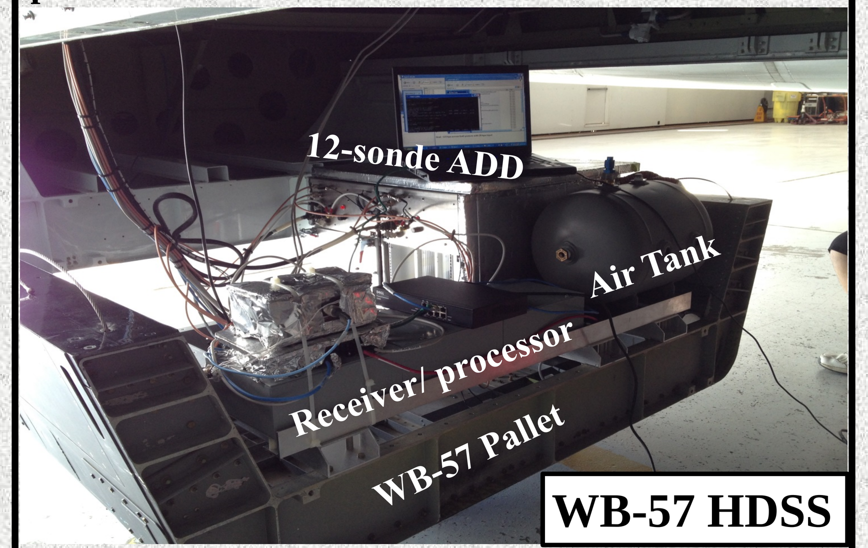
High Definition Sounding System (HDSS)

Twin Otter HDSS

HDSS as configured on the CIRPAS Twin Otter for 24-25 June, 2011 California Coast flights. Receiver/ processor mounted on rack to the left of the door.

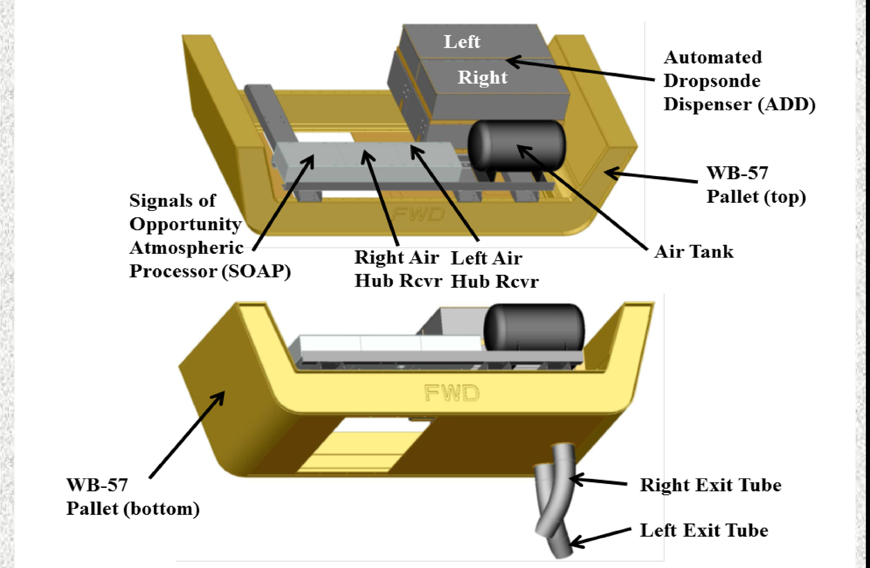


XDD (wt 58g, size 17.8x6.6 cm-upper) with printed circuit board, GPS and VHF antenna and sensor location (lower-left). Modified XDD (right) with black/white cardboard cylinder to minimize radiation effects.



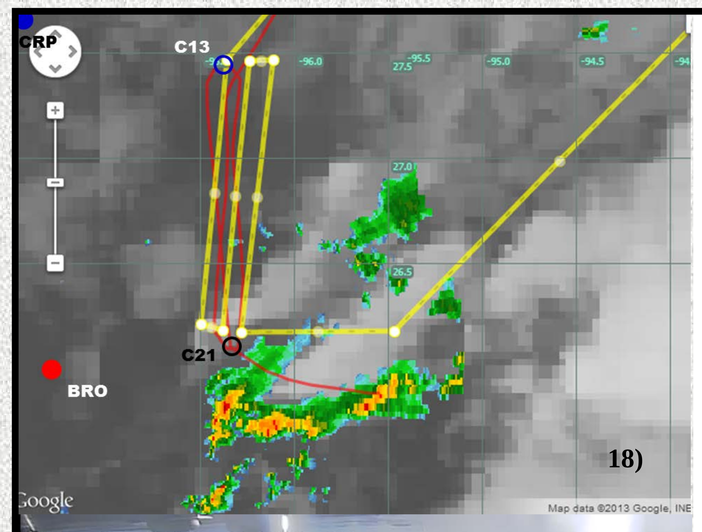
WB-57 HDSS

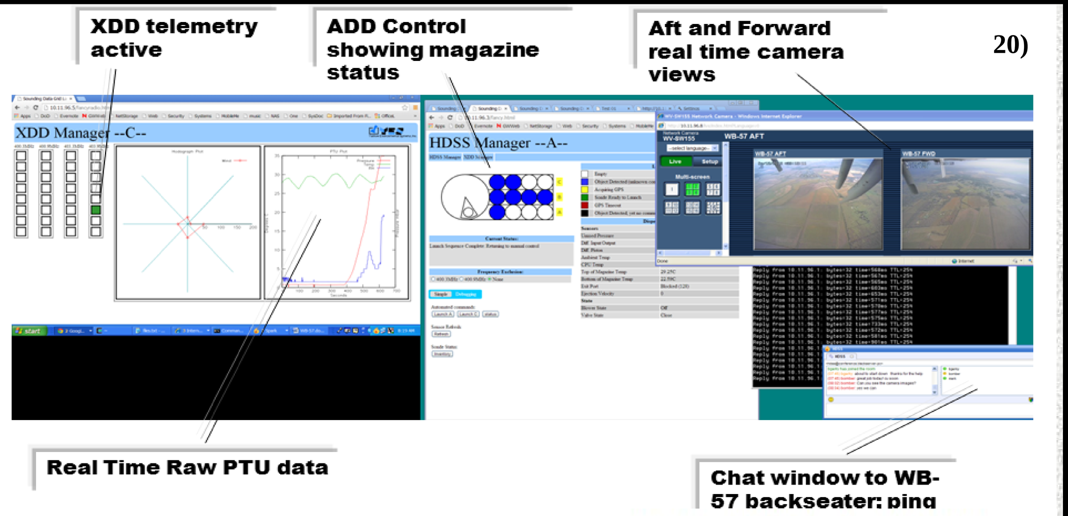
HDSS as configured on NASA WB-57 for 14-19 Nov, 2012 Texas Coast flights. Pallet is suspended below the aircraft by cables for instrument installation. Pallet is raised and secured to fuselage for flight.

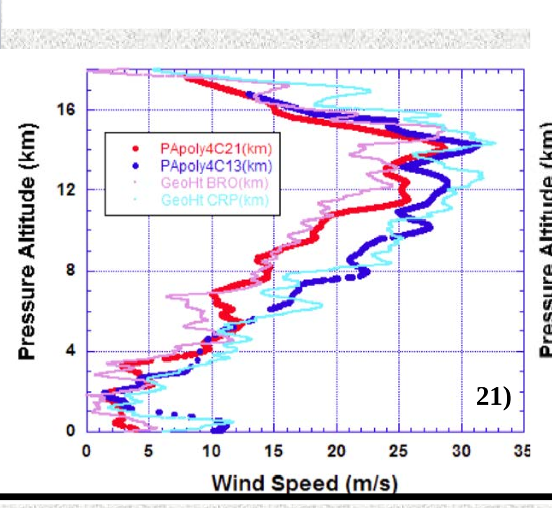


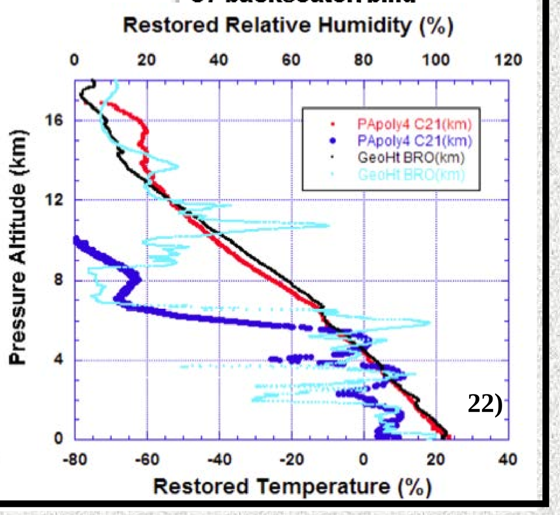
HDSS as configured for WB-57 showing top and bottom perspectives.

WB-57 Test Flight near Brownsville and Corpus Christi









Summary and Conclusions

A new instrumentation system for vertical atmospheric profiling has been introduced- the High-Definition Sounding System with its various components including the eXpendable Digital Dropsonde (XDD). Comparisons have been made with existing 'gold standard' instrumentation which indicates excellent ability to emulate and reproduce comparative measurements.

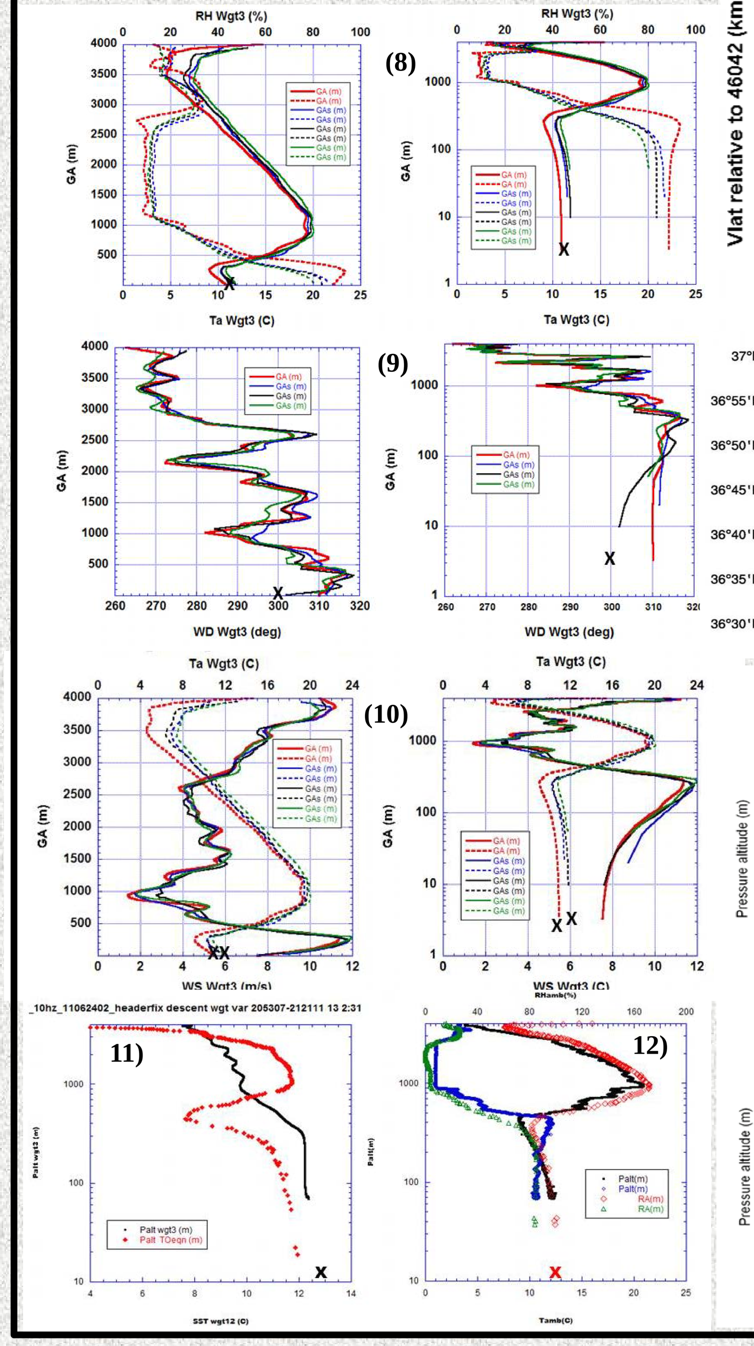
In this paper we describe the first field test of a new generation of atmospheric profilers, the XDD dropsonde. We have shown that this new system has the capability for atmospheric profile measurements at least as accurate as the present widely used RD-94 unit and accompanying high resolution aircraft profiling. We show that the new XDD sonde is a low noise unit, suggesting it may set a new standard in profiling precision, with speed random noise on the order of one-half meter per second, wind direction noise on the order of 6 degrees, temperature noise on the order of one-quarter degree Celsius and relative humidity noise on the order of half a percent. This is found to be superior to the current RD-94 dropsonde unit with corresponding noise figures of XX for wind speed, xx for wind direction and xx for humidity.

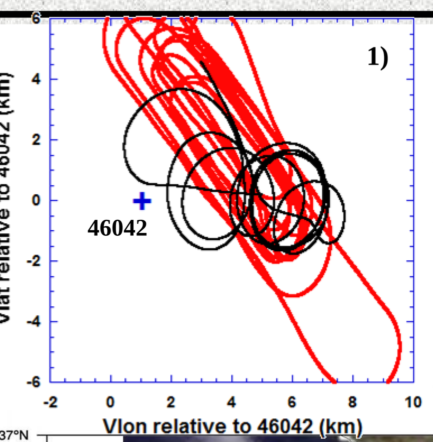
In the Twin Otter intercomparisons, both the XDD and RD-94 sondes showed they were able to provide repeatable profile observations to within about the same accuracy as the 'apparent signal noise', which appears to be dominated by real meteorological fluctuations in the variables. Comparison of the mean XDD profiles with the RD-94 and Twin Otter spiral descent observations showed that the XDD's were warmer by about 1C and drier by about 5% than the RD-94 and Twin Otter values. The twin Otter winds had to be heavily filtered due to oscillation associated with continuous heading changes during descent. However, the XDD and RD-94 winds were virtually identical during even small scale fluctuations in the vertical. The mean TO winds were also in good agreement although small scale fluctuations could not be resolved due to the required heavy filtering.

This experiment demonstrates promise for some new capabilities. In two of the XDD sondes, it was shown that the mini-radiometer had the capability for measuring skin SST to within 0.5C of in-situ moored buoy bulk SST at 1-m depth. Although by no means a conclusive sample, these initial results indicate promise for this new sensor. In addition, two other sondes were able to float on the surface for some tens of seconds and report air temperature observations that approached the mini-radiometer SST values. This two is a promising development in that proper design may allow for both radiometric SST values and in-situ values of SST to be observed.

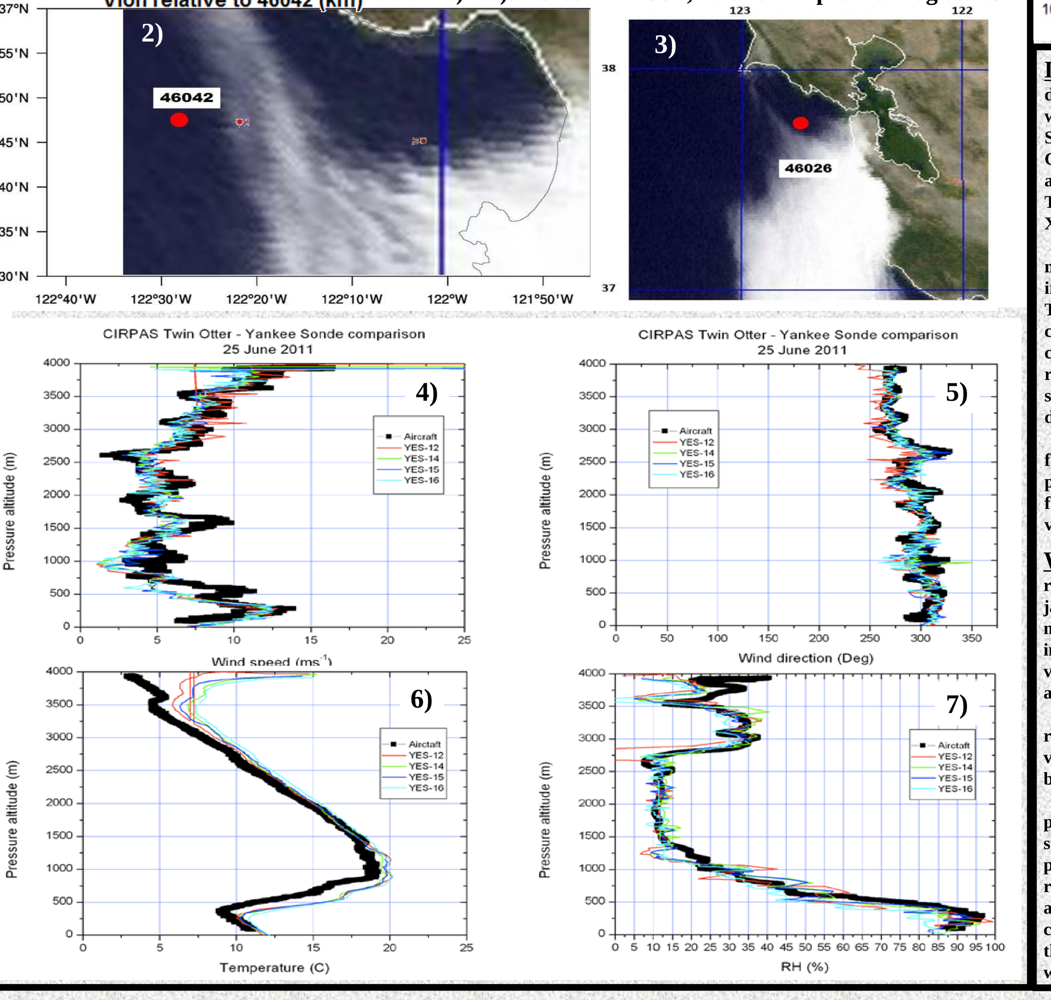
During the DC-8 XDD test flight conducted in the Eastern Tropical Pacific just east of decaying Tropical Storm Cosme and west of the Baja Penninsula, a total of 6 sondes were deployed: 3 in spiral dive mode (slow-fall) and 3 in ballistic mode (fast-fall). Mean descent rates of 13 and 25 m/s were observed, reaching the ground from 12-km deployment altitude in 16 and 9 minutes and at 240- and 130-km ranges, respectively. The slow spiral dive mode exhibited larger 'flight noise' amplitudes and greater numbers of data drop-outs than did the fast ballistic mode, especially in the fall velocity and horizontal winds. The latter was an order of magnitude lower than observed for the Twin Otter flights. Despite this, good agreement in gradually evolving smoothed profiles along the flight track were observed, especially in the thermodynamic variables of air temperature, relative humidity and sea surface temperature.

Twin Otter Test Flight

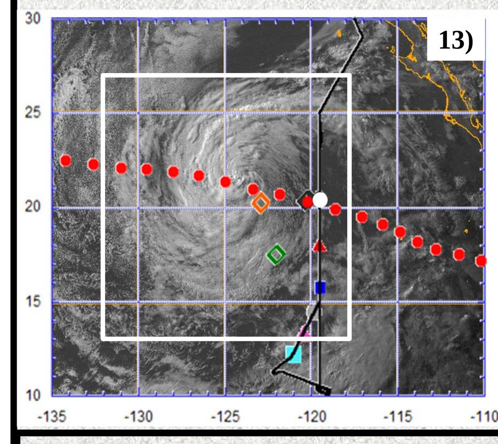


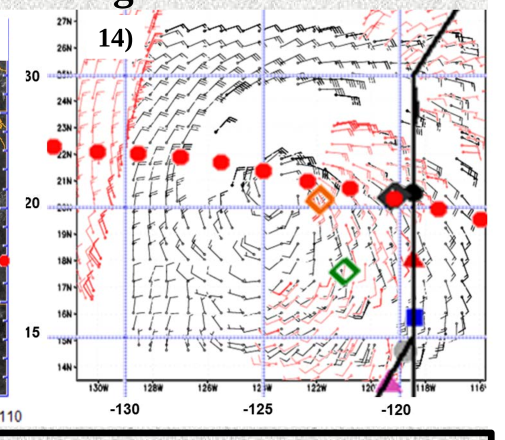


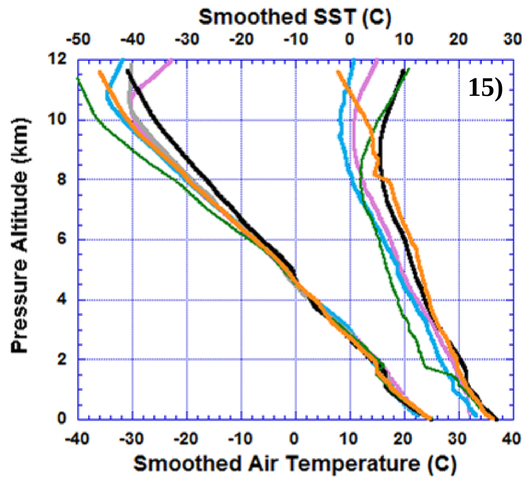
1) Spiral descent (black), racetrack ascent (red) near buoy 46042 for Monterey Bay 24 June flight.
2) VIS satellite image for time of 24 June flight.
3) VIS for time of San Francisco Bay 25 June flight .
4) – 5): Twin Otter (black) and XDD wind speed and direction profiles show excellent agreement.
6) - 7): Twin Otter and XDD air temperature and humidity show excellent agreement.
8) Air temperature and humidity profile comparisons between XDD (blue, black, green) and RD-94 (red), linear scale left, log scale right),with 'x' indicating buoy observation.
9)–10): Wind direction and speed profile comparisons.
11)–12): TO vs XDD SST, Ta and RH profiles- log scale.

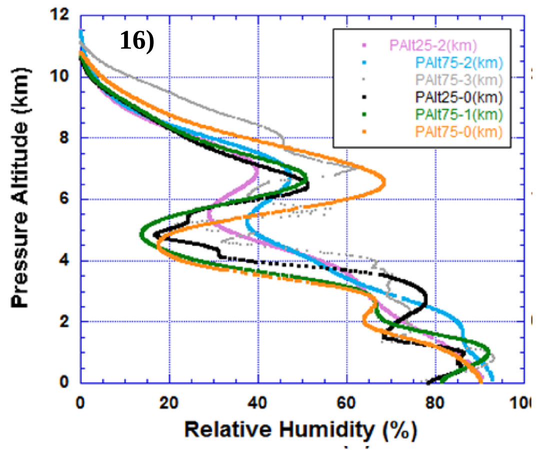


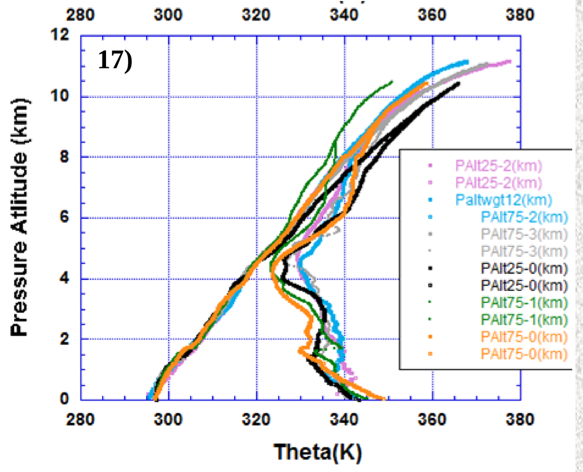
DC-8 Test Flight











DC-8 results: Three fast-fall sondes (magenta, pink and gray symbols) with average fall speed of 25 m/s were deployed from 0300-0330, 28 June, 2013 followed by 3 slow-fall sondes from 0330-0400 GMT, 28 June (blue, red and white symbols with average fall speed of 12 m/s). The sonde locations relative to Cosme's center ranged from 1000 km SSE for the first sonde to 450 km ESE for the last sonde. Fig 13 also shows the location of three SST drifting buoys. Ground truth estimates of SST from microwave SST products, as well as from the drift buoy observations showed good agreement with the sonde SST to within 0.5C. Fig 14 shows surface winds from AMSU and ASCAT satellite sensors. These observations indicate that surface winds along the DC-8 flight track were between 7-10 m/s, in good agreement with XDD surface winds.

Inspection of the air temperature and SST profiles in Fig 15 and the humidity in Fig 16 show that sharp changes measured by these sensors in the vicinity of an inversion layer at 1.5 km suggest adequate instrument response to resolve important small-scale atmospheric features. Of particular interest is the behavior of the SST for fast fall sonde 75-1 (green) The measured infrared SST increases as it passes through the inversion, while all the other sondes transition to a constant SST vs height across the inversion. This suggests that sonde 75-1 descended through a cloud layer measuring cold cloud top temperatures until it fell through the layer and again could see the surface. This behavior suggests relatively fast time response and realistic features in the observations. The decrease of humidity to near zero above 10 km suggests that the instrument cannot measure such low humidities, i.e. less than 10%, which is characteristic of most dropsonde observations.

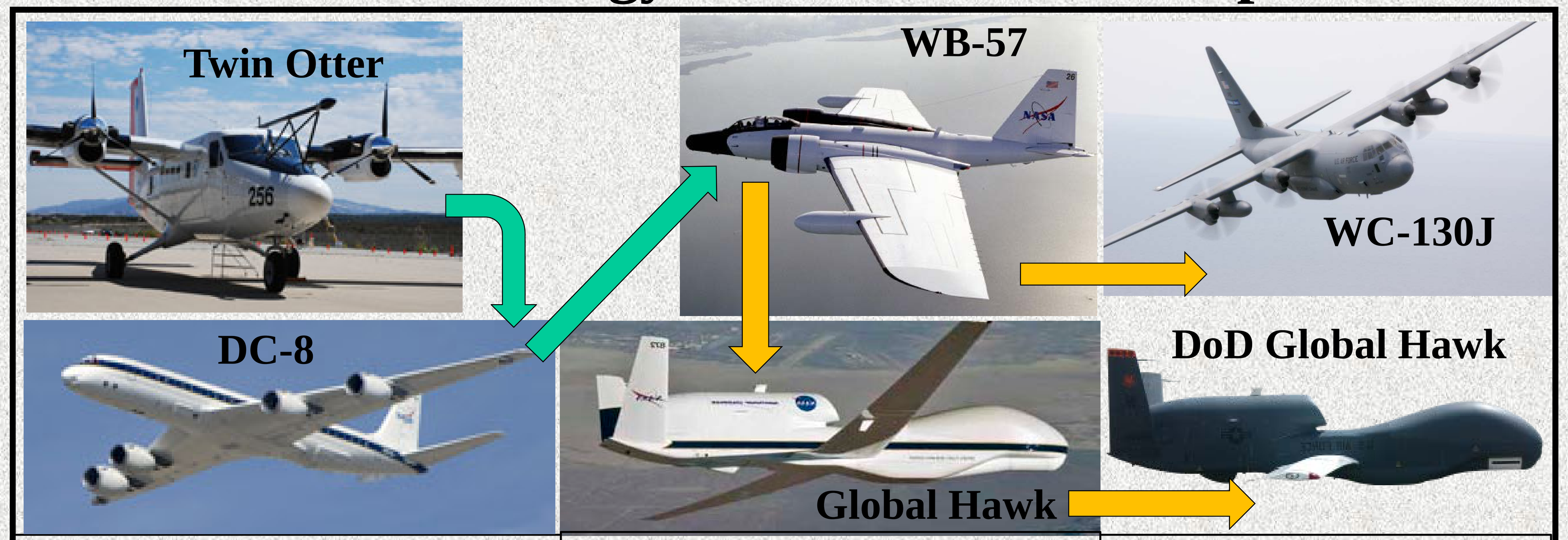
In Fig 17), the derived parameters of theta (left-most line group) and thetae (right-most line group) show similarity from sonde to sonde with little difference between fast fall and slow fall. Similar small-scale features seen in the thetae profiles suggest that realistic features are being resolved and that the measurements are repeatable. This conclusion is further substanitated by the wind speed and direction profiles (not shown). Boundary layer double wind maxima, with vertical scales on the order of 200 m, are resolved by several sondes.

WB-57 results: Planned (yellow) and actual (red) flight tracks the 19 Nov flight are superimposed upon a BRO radar image and GOES IR satellite image in fig. 18). Twenty three XDD dropsondes were successfully launched with no jams, and this included a less than one minute series of eight deployed in rapid succession, as the WB-57 flew over the mini-squall line just east of the south end of the track, shown from the forward looking HDSS camera in Fig. 19. Pilots injected XDDs into the turrets that were visible from the aircraft and from the HDSS aft- and forward-cameras that verified safe fuselage separation during ejection. Camera imagery conclusively showed each XDD falling away from the aircraft immediately, posing no threat to the aircraft, as seen in Fig. 19).

The HDSS web-based interface (Fig. 20) used to monitor the flight shows the status of XDD dropsondes not yet released in each of the two redundant ADD magazines, telemetry status of deployed XDDs, trajectory/PTU data plots, views from forward/aft cameras, status of the Ku-band communication link, and an ichat window for text communications between the mission scientist and the on-board WB-57 mission manager.

Fig. 21) shows excellent agreement between the two XDD's and corresponding NWS radiosonde-derived wind profiles deployed from Brownsville (BRO) and Corpus Christi (CRP). These profiles illustrate the vertical structure of a subtropical jet with different structures at CRP and BRO. This upper-level feature was just behind a cold front that had passed off the Texas coast the day before the flight. Of particular interest is the capability shown by this plot that the XDDs resolve all the fine scale detail measured by the radiosondes including fluctuations on the scale of 200-300m. Both the XDD and CRP radiosonde observed a low-level wind maximum (from the northeast) at the north end of the WB-57 racetrack, consistent with its position further behind the cold front and more well-established northeasterly flow. Fig. 22) illustrates the comparison of the temperature and humidity profiles observed from XDD dropsonde "C21" and the BRO radiosonde, which was excellent.

HDSS Technology Investment Roadmap



ACCOMPLISHMENTS

- Twin Otter DEMO: CA Coast June, 2011
- DC-8 DEMO: Baja California June, 2013
- WB-57 DEMO: TX Gulf Coast November, 2013

PLANS

- NASA HS3 Atlantic Global Hawk
- ONR TCI Atlantic WB-57 2014
- Proposed NOAA SHOUT Atlantic UAV DEMO Global Hawk 2015
- Proposed NASA OUTFLOW
- Proposed ONR TCI
- WPAC TC Intensity
- Global Hawk 2016-17

Future Technology Transfer

Operational Tropical Cyclone Reconnaissance

- DoD/NOAA Global Hawk
- Air Force WC-130J