Investigation of winds near the ocean surface using airborne Doppler Wind Lidar and dropsondes

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Focus on the lowest 50 meters of atmospheric MBL

• What is the “true” wind at the traditional 10 meter reference height over water, especially for wind speeds >15m/s?

• What do airborne Doppler Wind Lidars (DWL) and dropsondes have to contribute to the calibration of OVWs, especially in conditions of U10>15m/s?

• Two specific issues today:
  • What is the height assignment precision of the HDSS (dropsonde) wind information?
  • How are the DWL wind retrievals below 50m to be used in studies of the Marine Boundary Layer with >15m/s winds?
Overview

• Lowest 50m of the PBL is just one focus area of a more comprehensive series of multi-agency (NASA, ONR and NOAA) funded investigations of the PBL (mostly over water) using airborne Doppler Wind Lidars, dropsondes and other remote sensing capabilities.

• PolarWinds (NASA DC8) 2015, Iceland: > 80 hours DWL time and ~100 dropsondes.

• CPEX (NASA DC8) 2017, Florida: >100 hours DWL time and ~ 300 dropsondes.

• Hurricane Reconnaissance (NOAA P3) 2015-2018, Florida: > 100 hours DWL time and ~ 100 dropsondes

• Aeolus cal/val preparations(NASA DC8) 2019, California: ~45 DWL hours and 64 dropsondes.
**Doppler Aerosol Wind (DAWN) Lidar System**

**Instrument PI:** Michael J. Kavaya, NASA LaRC

**Science PI:** G. D. Emmitt, SWA

### DAWN Capabilities

High coherent Doppler lidar sensitivity to aerosol backscatter, enabling excellent vertical resolution, accuracy, and atmospheric coverage.

Provides vertical profiles of horizontal wind vectors, LOS range wind and wind turbulence profiles, and relative aerosol backscatter profiles.

Optional number of azimuth angles (up to 12) permits trade of wind variability determination vs. horizontal resolution.

Optional number of laser shots averaged for each LOS wind profile permits trade of atmospheric coverage vs. horizontal resolution.

Data may be processed multiple ways to provide various combinations of vertical and horizontal resolution, atmospheric coverage, and expected accuracy statistics.

### Attribute

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
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<tbody>
<tr>
<td><strong>Airplanes Flown</strong></td>
<td>DC-8 and UC-12B</td>
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<tr>
<td><strong>Solid-State Laser Crystal and Wavelength</strong></td>
<td>Ho:Ti:Lu2F4, 2.053 Microns</td>
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<td><strong>Laser Architecture</strong></td>
<td>Master Oscillator Power Amplifier (MOPA)</td>
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<td><strong>Pumping Source, Wavelength, Duration</strong></td>
<td>100mJ, 10HZ, 180ns</td>
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<td>InGaAs, Coherent, Dual-Balanced</td>
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<td><strong>Scanner Diameter, Type, Deflection</strong></td>
<td>15 cm, Step-Stare Rotating Wedge, 30° About Nadir</td>
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<tr>
<td><strong>Eye Safety</strong></td>
<td>Safe at any Range When DAWN Closed Up for Flight</td>
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<tr>
<td><strong>Pointing Knowledge Technique</strong></td>
<td>Dedicated INS/GPS on Lidar; dry land returns</td>
</tr>
<tr>
<td><strong>LOS Wind Measurement Precision</strong></td>
<td>&lt; 1 m/s</td>
</tr>
<tr>
<td><strong>Maximum LOS, Horizontal Wind</strong></td>
<td>±180 m/s, ±160 m/s</td>
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<tr>
<td><strong>Captured Data Length in Range, Altitude</strong></td>
<td>0 – 16.4 km, 0 – 14.2 km</td>
</tr>
<tr>
<td><strong>Vertical Resolution</strong></td>
<td>133 m for 512 Sample Range Gate</td>
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</table>

As used in CPEX

**Vertical resolution:** 66/33m

**Single shot horizontal resolution in PBL:** <20m

**Lowest level of wind retrieval:**

\[ \sim 16m \text{ using SRGs} \]

**Full tropospheric profiles using 2 second stares from surface to 12km**
HDSS dropsonde developed by ONR by YES

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.
HDSS and XDD Overview

The HDSS (High Definition Sounding System) and eXpendable Digital Dropsonde (XDD) developed by Yankee Environmental Systems through ONR (Black et al., 2017) was used. Before CPEX this dropsonde system had been deployed over the past seven years including:


The HDSS was selected for three primary advantages over prior dropsonde technologies:

- **High fall speeds** (~30m/s – 18m/s) reduces horizontal drift distances which is highly desirable in the proximity of organized convection
- **Surface temperature sensor** was seen as particularly important near and under deep convection generating cold pools
- **>12 simultaneous sonde tracking capability** enables rapid deployment in areas which the science team identified as meeting mission priority.
### Near Surface Wind Comparisons Near Buoys (CPEX)

<table>
<thead>
<tr>
<th>CPEX Mission</th>
<th>DAWN (~50m)</th>
<th>Buoy (id #)</th>
<th>Dropsonde (~20m)</th>
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<td>May 27, 2017</td>
<td>4.3/110</td>
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<td>June 1, 2017</td>
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<td>3.6/146 (42003)</td>
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<td>June 16, 2017</td>
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<td>3.7/162 (VCAF1)</td>
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<td>13.5/161</td>
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<td>June 20, 2017</td>
<td>12.6/162</td>
<td>11.7/352 (42395)</td>
<td>9.7/ 10</td>
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<tr>
<td>June 21, 2017</td>
<td>10.5/192</td>
<td>9.0/167 (42001)</td>
<td>11.6/168</td>
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</table>

- Dropsonde has high speed bias and clockwise directional bias.
Evaluation of the HDSS data below 50m in MBL

• On-going at both YES and SWA with funding from NASA and ONR.
• The nominal fall speed of the HDSS in the last second before “splash down” is ~18m/s.
• The sonde broadcasts a data packet once per second that contains 2 and 4 Hz information.
• The computed geopotential height is trusted over the GPS report height near the ocean surface.
• Recent questions raised by the OVWs and NWP communities have initiated an investigation into the last second of data transmission
• **Current finding:** the height assignments for HDSS GPS winds is off by 1.53 seconds or ~28 meters. Thus the U10 winds are biased high...still looking for truth for comparisons.
DAWN/Drop Comparison setup

• Ground return calibration for DAWN while over Florida peninsula
  • Straight and level between 3 and 4 km AGL
  • Perform calibration flight segment before and after an over-water mission
    clouds and ATC permitting.

• 162 (out of 325) CPEX dropsondes over 16 flights were used in the
  comparisons (~15,000 height segments of ~ 66 meter DWL vertical
  resolution)
Example of attitude calibration for DAWN during CPEX

Residual ground speed = .045 m/s
Example ground return calibrations with residual ground speed (Nominal DC-8 groundspeed during calibration is 175m/s)

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<thead>
<tr>
<th>Date</th>
<th>Yaw Correction</th>
<th>Pitch Correction</th>
<th>Ground Speed(m/s)</th>
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<td>-0.30</td>
<td>-0.30</td>
<td>0.037</td>
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<td>May 29</td>
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<td>-0.30</td>
<td>0.199</td>
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<td>+0.05</td>
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<td>0.023</td>
<td>-0.018</td>
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<td>June 24</td>
<td>-0.15</td>
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<td>0.037</td>
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DAWN vs dropsonde sampling comparisons

Dropsonde: 30 - 20 m/s fall speeds
Time in flight: 8000 m in ~5.3 minutes
DC-8 ground distance: ~ 65 km
Horizontal drift (10 m/s wind): 3.2 km

DAWN: ~10 seconds sampling +9 seconds overhead per sounding (3.8 km)

Co-located ~ within 5 km  Coincident ~ 5 minutes
Example DAWN-Dropsonde comparison during CPEX 2017
DAWN-Dropsonde comparisons from CPEX 2017
Wind Speed (m/s)

<table>
<thead>
<tr>
<th></th>
<th>Number 37m seg</th>
<th>MEAN Z DIFF (m)</th>
<th>BIAS (m/s)</th>
<th>MEAN ABS (ΔWS)</th>
<th>ΔWS RMSD</th>
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<tbody>
<tr>
<td>ALL</td>
<td>15517</td>
<td>3.08</td>
<td>0.09</td>
<td>1.13</td>
<td>1.55</td>
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<tr>
<td>2 LOOK</td>
<td>6921</td>
<td>3.26</td>
<td>0.05</td>
<td>1.28</td>
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<td>5 LOOK</td>
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<td>2.93</td>
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## Differences by wind speed interval (m/s)

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<th>Wind Speed Interval</th>
<th>Number 37m seg</th>
<th>MEAN Z DIFF (m)</th>
<th>BIAS (m/s)</th>
<th>MEAN ABS(ΔWS)</th>
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<tbody>
<tr>
<td>0-5 m/s</td>
<td>3193</td>
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<td>1.38</td>
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<tr>
<td>5-10 m/s</td>
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<td>3.00</td>
<td>0.10</td>
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<td>1.47</td>
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<td>10-15 m/s</td>
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<td>&gt;15 m/s</td>
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<table>
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<th>BIAS (deg)</th>
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<th>ΔWD RMSD</th>
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### Differences by height interval (km)

<table>
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<th>Height Interval</th>
<th>Number 37m seg</th>
<th>MEAN Z DIFF (m)</th>
<th>BIAS (m/s)</th>
<th>MEAN ABS(ΔWS)</th>
<th>ΔWS RMSD</th>
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<tbody>
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<td>0-3 km</td>
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<td>-0.02</td>
<td>0.95</td>
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<td>3-6 km</td>
<td>2079</td>
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<td>0.26</td>
<td>1.20</td>
<td>1.62</td>
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<tr>
<td>6-9 km</td>
<td>5774</td>
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<td>0.27</td>
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<tr>
<td>9-12 km</td>
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<table>
<thead>
<tr>
<th>Height Interval</th>
<th>Number 37m seg</th>
<th>MEAN Z DIFF (m)</th>
<th>BIAS (deg)</th>
<th>MEAN ABS(ΔWD)</th>
<th>ΔWD RMSD</th>
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<tbody>
<tr>
<td>0-3 km</td>
<td>4935</td>
<td>2.52</td>
<td>1.62</td>
<td>9.79</td>
<td>17.5</td>
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<td>3-6 km</td>
<td>2079</td>
<td>2.91</td>
<td>0.78</td>
<td>10.10</td>
<td>18.4</td>
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<td>6-9 km</td>
<td>5774</td>
<td>3.32</td>
<td>0.31</td>
<td>14.25</td>
<td>26.4</td>
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<tr>
<td>9-12 km</td>
<td>2732</td>
<td>3.70</td>
<td>-0.68</td>
<td>8.09</td>
<td>11.88</td>
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</table>
All DAWN – Dropsonde Comparisons from 2017 CPEX (162 ~ co-located, coincident DAWN and Dropsonde Profiles)

CPEX DAWN-DROPSONDE COMPARISON - ALL WIND SPEED

$R^2 = 0.98153$

CPEX DAWN-DROPSONDE COMPARISON - ALL WIND DIRECTION

$R^2 = 0.96732$
Focus on the lowest 50m with airborne DWL
Example 1 from DAWN during CPEX
Focus on lowest 200m using sliding gates
Example 2

[Diagram showing LOS SNR, Wind Speed, and Wind Direction with various data points and labels.]
Lowest 200m under white cap conditions
High wind conditions
Simulations of Airborne DWL measurements within the lowest 50ms over water
DWL pulse for 4 positions relative to ocean surface
Backscatter: white caps with spray below 10m
Return signal within range gate
Wind profile using .14 coefficient in power law
Wind speed per DWL in lowest 50m

Return from the spray zone begins domination
Summary

- HDSS sondes may be reporting winds between 20 and 30 meters as much nearer the surface. The average event time error is 1.53 seconds which translates to ~28m with fall speeds of 18m/s.

- The airborne Doppler Wind Lidar (NASA’s DAWN) makes retrievals down to the surface using sliding variable and adaptable gates on the raw digitized return. However:
  - Below 50 meters above the water surface the retrievals are heavily dependent upon the backscatter structures.
  - At low wind speeds the near surface (< 10m) values are reported at heights below the surface (can be adjusted after the processing).
  - At high winds speeds with whitecaps and water/salt sprays, the speed of the spray is reported starting at gate altitudes around 50m.

- Recent investigations of high wind situations has revealed a possible method for retrieving winds at and below 10ms with an airborne DWL.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor type/data rate</th>
<th>Accuracy</th>
<th>Resolution</th>
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<td>Temperature</td>
<td>Thermistor/2 Hz/1 Hz</td>
<td>.148 degC</td>
<td>0.0168 degC</td>
</tr>
<tr>
<td>Pressure</td>
<td>MEMS/2–1 Hz</td>
<td>1.5 hPa at 25C</td>
<td>2.5 hPa</td>
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<tr>
<td>Humidity</td>
<td>MEMS/2–1 Hz</td>
<td>1.8% at 25C</td>
<td>0.1%</td>
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<tr>
<td>SST</td>
<td>IR micro-radiometer</td>
<td>0.2 at 25C</td>
<td>0.0168C</td>
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<tr>
<td></td>
<td>9–11 mm/1 Hz</td>
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</table>
Current cases from CPEX being used to evaluate buoy/drop/DWL 10m winds

<table>
<thead>
<tr>
<th>Date</th>
<th>Time(GMT)</th>
<th>HDSS(LH)</th>
<th>HDSS(WS)</th>
<th>HDSS(WD)</th>
<th>DAWN(HT)</th>
<th>DAWN(WS)</th>
<th>DAWN(WD)</th>
<th>Buoy WS</th>
<th>Buoy WD</th>
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<td>100.7</td>
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Other Cases

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<th>Date</th>
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<th>HDSS(WS)</th>
<th>HDSS(WD)</th>
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<th>DAWN(WD)</th>
<th>Buoy WS</th>
<th>Buoy WD</th>
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Wind Speed in m/s
Height in meters above surface (MSL)
Another high wind case
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