Preliminary Comparisons of DAWN, Dropsonde and Aeolus Wind Observations

Steven Greco¹, G.D. Emmitt¹, S.A. Wood¹ and Sharon Rodier²

¹ – Simpson Weather Associates, Charlottesville, VA; ² – LARC-E304/SSAI, Hampton, VA

Working Group Meeting for Space Lidar Winds
Hampton, Virginia
July 10-11, 2019
Airborne DAWN Underflights of Aeolus

- April 17-30, 2019 NASA Airborne Campaign
- Based out of Palmdale, CA
- Airborne DAWN and YES Dropsonde aboard NASA DC-8
- 5 underpasses of Aeolus in April 2019
- Over the eastern Pacific Ocean
  - Two transects between US west coast and Hawaii
  - **Three missions off west coast of US (30 – 50 N)**
    - Mostly clear to partly cloudy conditions
    - Low and high aerosol segments
DAWN Wind Measurements

- DAWN
  - 2 micron coherent
  - 5Hz, 20 shots per look for April flights
- DAWN wind vector products are low bias (< .25m/s) and good RMSD in comparisons with dropsondes (see next slide)
- 3-D Wind Profiles computed for 5-look DAWN scanning pattern (5 LOS)
  - 20 shot integration
  - 4-5km horizontal resolution
  - 75m vertical resolution along LOS
  - 33m resolution for vertical profiles
- U and V of DAWN profile used to compute a DAWN Aeolus projection of HLOS for every scan
DAWN data quality

**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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALL</strong></td>
<td>15517</td>
<td>3.08</td>
<td>0.09</td>
<td>1.13</td>
<td>1.55</td>
</tr>
<tr>
<td><strong>2 LOOK</strong></td>
<td>6921</td>
<td>3.26</td>
<td>0.05</td>
<td>1.28</td>
<td>1.72</td>
</tr>
<tr>
<td><strong>5 LOOK</strong></td>
<td>8596</td>
<td>2.93</td>
<td>0.13</td>
<td>1.01</td>
<td>1.39</td>
</tr>
</tbody>
</table>

**DAWN-Dropsonde comparisons from CPEX 2017**

**Wind Direction (degrees)**

<table>
<thead>
<tr>
<th></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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALL</strong></td>
<td>15517</td>
<td>3.08</td>
<td>0.62</td>
<td>11.19</td>
<td>20.69</td>
</tr>
<tr>
<td><strong>2 LOOK</strong></td>
<td>6921</td>
<td>3.26</td>
<td>0.68</td>
<td>12.66</td>
<td>24.10</td>
</tr>
<tr>
<td><strong>5 LOOK</strong></td>
<td>8596</td>
<td>2.93</td>
<td>0.56</td>
<td>10.01</td>
<td>17.44</td>
</tr>
</tbody>
</table>
Aeolus LOS Wind Product

• Non-scanning single LOS for Rayleigh and Mie channels
  • During April underflights the first laser was operating at nearly 50% of the design optical power
  • Not all biases or best calibration data have been accounted for in the preliminary comparison to be shown here
• Using Level 2B data for comparison
  • RAYLEIGH CLEAR
  • RAYLEIGH CLOUDY
  • MIE CLEAR product
  • MIE CLOUDY product

• Rayleigh derives wind from molecular returns
  • Baseline horizontal integration: ~85km; 24 vertical levels
  • Vertical coverage - ~ 250-500m in PBL to 1km in troposphere
  • Rejection – observation error quantifier > 6.6 m/s (below 200 mb)

• Mie derived winds from clouds and aerosols
  • Horizontal integration: ~ 10-12 km; 24 vertical levels
  • Vertical resolution: in bottom 1km; 500m; 250-400m for 1-4km; 1km > 4km
  • Rejection – observation error quantifier > 4.5 m/s
0430 DAWN-AEOLUS HLOS COMPARSIONS

1) AEOLUS S-N 02:27 - 02:29Z
2) DAWN N-S 02:13 – 02:54Z (~ 600 km)
3) DAWN profiles from 5 Looks computed every ~5km
4) 7 AEOLUS profiles along DAWN under-flight track
   - Rayleigh Clear (uses 21-24 winds)
   - Mie Cloudy (uses 1-4 winds)
4) DAWN Aeolus projection HLOS shown for 123 DAWN profiles along DAWN underflight
5) 7 DAWN “Integrated” profiles each utilizing 17 individual DAWN profiles to match
   Aeolus Level 2B resolution
DAWN-DROP COMPARISON MIDDLE OF UNDERFLIGHT
AEOLUS DIRECTLY OVERHEAD

X – Mie Cloudy
1) AEOLUS S-N 02:28 - 02:29Z
2) DAWN N-S 02:06 – 02:53Z (~ 600 km)
3) DAWN profiles from 5 Looks computed every ~5km (119 profiles)
4) 7 AEOLUS profiles along DAWN under-flight track
   - Rayleigh Clear (21-24 winds used)
   - Mie Cloudy (1-4 winds used)
4) DAWN Aeolus projection HLOS shown for 123 DAWN profiles along DAWN underflight
5) 7 DAWN “Integrated” profiles each utilizing 17 individual DAWN profiles to match Aeolus Level 2B resolution
DAWN DROP COMPARISON MIDDLE OF UNDERFLIGHT
0423 Underflight DAWN-Aeolus Profile Comparison (Aeolus #350)

- DAWN
- Aeolus Rayleigh Clear

X – Mie Cloudy
AEOLUS DIRECTLY OVERHEAD

0423 Underflight DAWN-Aeolus Profile Comparison (Aeolus #354)

- DAWN
- Aeolus Rayleigh Clear

X – Mie Cloudy

Altitude (m)

HLOS Wind Speed (m/s)
0418 DAWN-AEOLUS HLOS COMPARSIONS

1) AEOLUS S-N 02:56 - 03:00Z
2) DAWN N-S 01:51 – 03:32Z
3) 7 AEOLUS profiles along DAWN under-flight track
   - Rayleigh Clear (21-24 winds)
   - Mie Cloudy (1-4 winds)
4) DAWN mostly operated in STARE (1 Look) mode, only small portion of underflight where full profiles measured
5) DAWN SNR and Aeolus projection HLOS shown for 30 DAWN profiles along DAWN under-flight (but other short segments of 2-4 scans/profiles)
DAWN-DROP COMPARISON MIDDLE OF UNDERFLIGHT

**0418 DAWN-DROP Comparison - Wind Speed (m/s)**

- **Dropsonde**
- **DAWN**

**0418 DAWN-DROP Comparison - Wind Direction (deg)**
AEOLUS DIRECTLY OVERHEAD

X – Mie Cloudy
Summary

• Preliminary comparisons
  - Neither data set final
  - More experience needed working with Aeolus products
• DAWN performed well in relatively clean/low aerosol and low to partly cloud conditions
  - Comparison with Dropsondes
  - Often complete profiles
• Even with weakened laser in April 2019, very encouraging comparisons between DAWN and Aeolus
  • RAYLEIGH Clear
• More work to follow
ADDITIONAL SLIDES
Doppler Aerosol Wind (DAWN) Lidar System

Instrument PI: Michael J. Kavaya, NASA LaRC

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.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airplanes Flown</td>
<td>DC-8 and UC-12B</td>
</tr>
<tr>
<td>Solid-State Laser Crystal and Wavelength</td>
<td>Ho:TimLuLiF, 2.053 Microns</td>
</tr>
<tr>
<td>Laser Architecture</td>
<td>Master Oscillator Power Amplifier (MOPA)</td>
</tr>
<tr>
<td>Pumping Source, Wavelength, Duration</td>
<td>Laser Diode Arrays (LDA), 792 nm, 1 ms</td>
</tr>
<tr>
<td>Laser Pulse Energy E, Rate f, FWM Duration t</td>
<td>100 mJ, 10 Hz, 180 ns</td>
</tr>
<tr>
<td>Telescope Diameter D, Magnification M</td>
<td>15 cm, 20</td>
</tr>
<tr>
<td>Light Detection Material, Technique</td>
<td>InGaAs, Coherent, Dual-Balanced</td>
</tr>
<tr>
<td>Scanner Diameter, Type, Deflection</td>
<td>15 cm, Step-Stage Rotating Wedge, 30° About Nadir</td>
</tr>
<tr>
<td>Eye Safety</td>
<td>Safe at any Range When DAWN Closed Up for Flight</td>
</tr>
<tr>
<td>Pointing Knowledge Technique</td>
<td>Dedicated INS/GPS-on-Lidar; dry land returns</td>
</tr>
<tr>
<td>LOS Wind Measurement Precision</td>
<td>&lt; 1 m/s</td>
</tr>
<tr>
<td>Maximum LOS, Horizontal Wind</td>
<td>±80 m/s, ±160 m/s</td>
</tr>
<tr>
<td>Captured Data Length in Range, Altitude</td>
<td>0 – 16.4 km, 0 – 14.2 km</td>
</tr>
<tr>
<td>Vertical Resolution</td>
<td>133 m for 512-Sample Range Gate</td>
</tr>
</tbody>
</table>
Comparison setup

- Ground return calibration 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 time permitting.
  - Major changes in the DAWN system were made on June 17th.
- Calibration products:
  - Pitch correction (~0.5 degrees)
  - Yaw correction (~0.5 degrees)
  - Roll correction (~< 0.01 degrees)
  - Height correction (timing of outgoing pulse)
  - Unknowns folded into the pitch corrections (~< 0.02 degrees)
- No other corrections made to the DAWN data prior to dropsonde comparisons.
- 162 dropsondes over 14 flights were used in the comparisons (~15,000 height segments of ~66 meter DWL vertical resolution)
- Used only DAWN high resolution (66m processing gates and 33m display gates)
Example DAWN-Dropsonde comparison during CPEX 2017

CPEX DAWN - DROPSonde COMPARISON
Wind Speed
06/11/17
Dropsonde (145236) - Black Line
DAWN (145402) - Green Line

CPEX DAWN - DROPSonde COMPARISON
Wind Direction
06/11/17
Dropsonde (145236) - Black Line
DAWN (145402) - Green Line
Differences by height interval (km)

<table>
<thead>
<tr>
<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>
</tr>
</thead>
<tbody>
<tr>
<td>0-3 km</td>
<td>4935</td>
<td>2.52</td>
<td>-0.02</td>
<td>0.95</td>
<td>1.26</td>
</tr>
<tr>
<td>3-6 km</td>
<td>2079</td>
<td>2.91</td>
<td>0.26</td>
<td>1.20</td>
<td>1.62</td>
</tr>
<tr>
<td>6-9 km</td>
<td>5774</td>
<td>3.32</td>
<td>0.27</td>
<td>1.14</td>
<td>1.58</td>
</tr>
<tr>
<td>9-12 km</td>
<td>2732</td>
<td>3.70</td>
<td>-0.20</td>
<td>1.38</td>
<td>1.84</td>
</tr>
</tbody>
</table>

<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>
</tr>
</thead>
<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>
</tr>
<tr>
<td>3-6 km</td>
<td>2079</td>
<td>2.91</td>
<td>0.78</td>
<td>10.10</td>
<td>18.4</td>
</tr>
<tr>
<td>6-9 km</td>
<td>5774</td>
<td>3.32</td>
<td>0.31</td>
<td>14.25</td>
<td>26.4</td>
</tr>
<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>
</tr>
</tbody>
</table>