# Evaluating airborne DAWN's accuracy in preparation for AEOLUS under flights with NASA's DC-8

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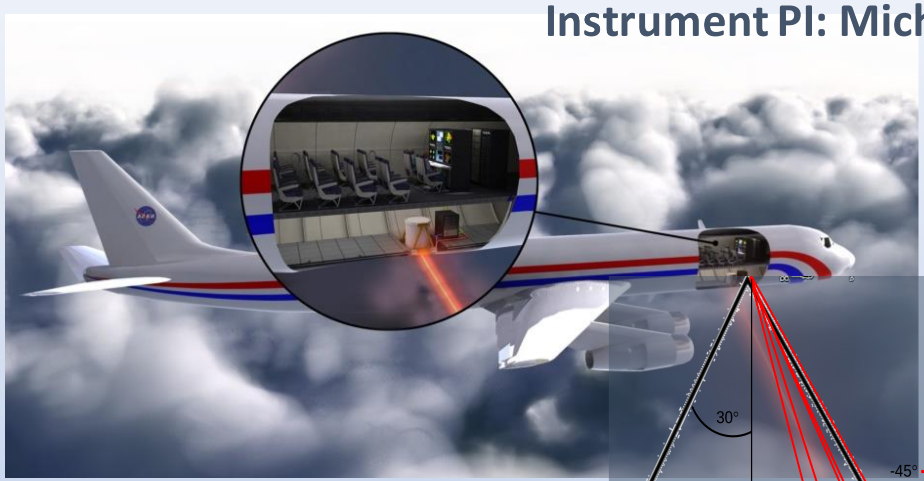
# Preparation for Aeolus Cal/Val 2019

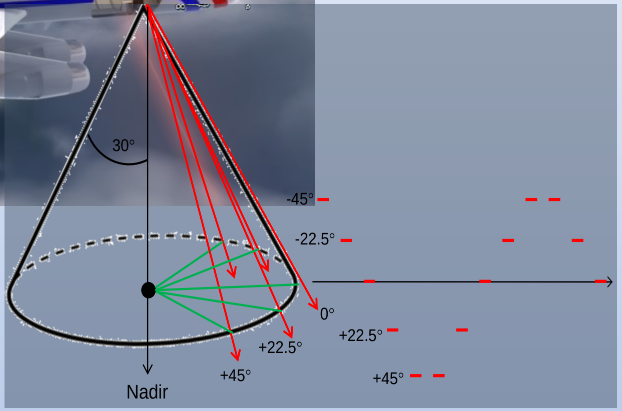
- **NASA is conducting a short-duration airborne campaign with their DC-8 aircraft to:**
  - Under fly Aeolus to demonstrate Cal/Val with high spatial resolution wind and aerosol observations
  - Demonstrate NASA wind, aerosol, and water vapor lidar systems' performances
  - Begin to address wind and PBL-related science questions laid out in the National Academy of Sciences' Decadal Survey
- **43 NASA DC-8 flight hours (Up to 7 flights) out of Palmdale, CA from 15-30 April 2019**
  - 25 flight hours to target clear sky and broken cloud regions with vertical and horizontal wind gradients, and explore other targets of opportunity in the Eastern Pacific Ocean
  - 18 flight hours to occur across a 2-day flight to/from Kona, Hawaii to explore a climatological aerosol maximum in April 2007-2015 CALIPSO data over the Eastern Pacific (~10º N, 135º W)

More on this campaign from Kris Bedka this afternoon

# Doppler Aerosol Wind (DAWN) Lidar System

Instrument PI: Michael J. Kavaya, NASA LaRC






Demonstrated in CPEX

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

Vertical resolution: 66/33m
Single shot horizontal resolution in PBL: <20m
Lowest level of wind retrieval: ~ 16m using SRGs
Full tropospheric profiles using 2 second stares from surface to 10km

## 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

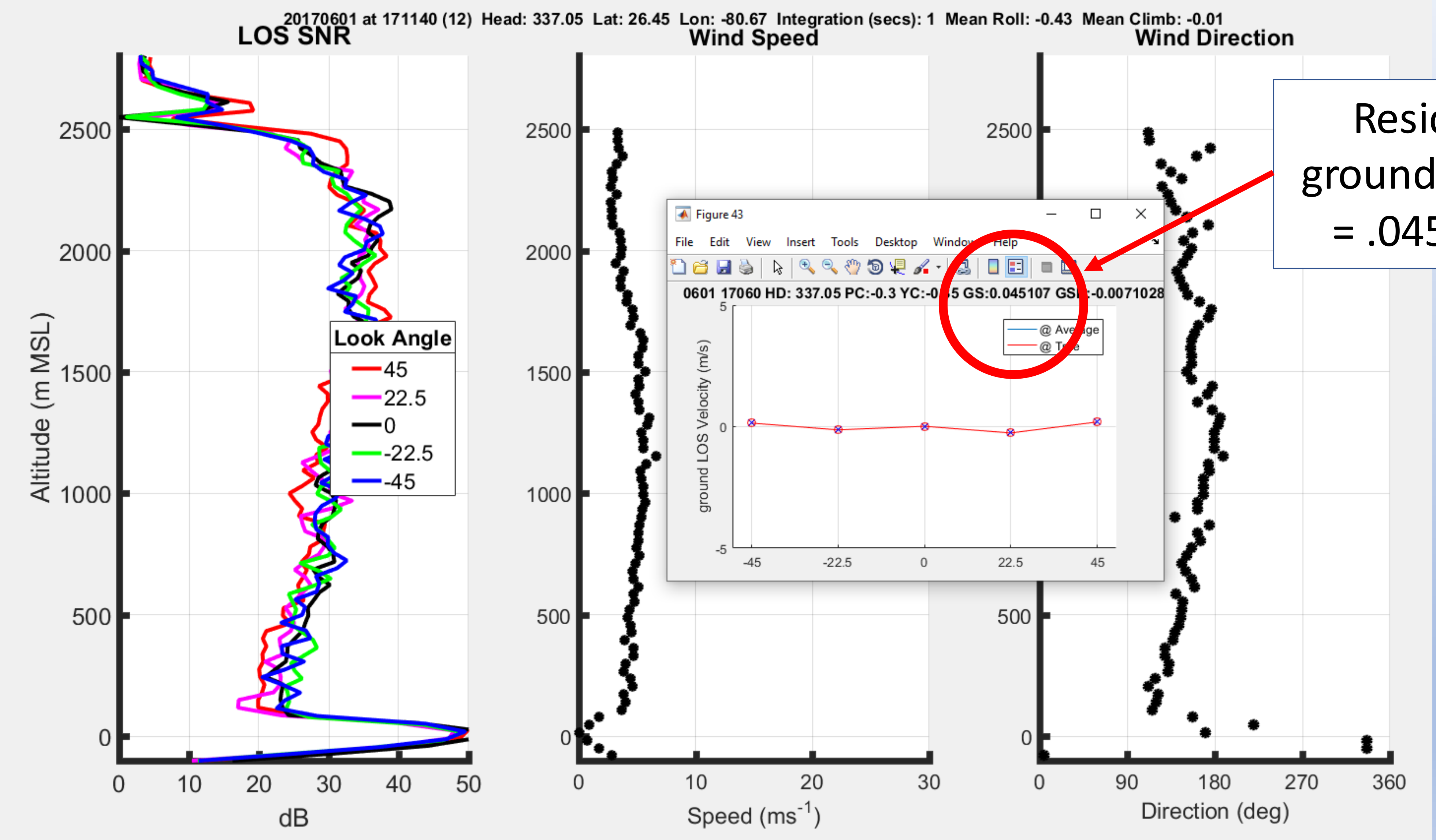
Optional number of laser shots averaged for each LOS wind profile permits trade of atmospheric coverage vs. horizontal resolution

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

# 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 ATC permitting.
  - Major changes in the DAWN system were made on June 17th.
  - Calibration products:
    - Pitch correction (~.5 degrees)
    - Yaw correction (~.5 degrees)
    - Roll correction (~ < .01 degrees)
    - Height correction (timing of outgoing pulse)
    - Unknowns folded into the pitch corrections (< .02 degrees)
  - No other corrections made to the DAWN data prior to dropsonde comparisons.
- 162 dropsondes over 16 flights were used in the comparisons (~15,000 height segments of ~ 66 meter DWL vertical resolution)
- Used only DAWN high resolution (75m LOS processing gates and 37m display gates); removed LOS gates not meeting SNR threshold.

# Example of attitude calibration for DAWN during CPEX



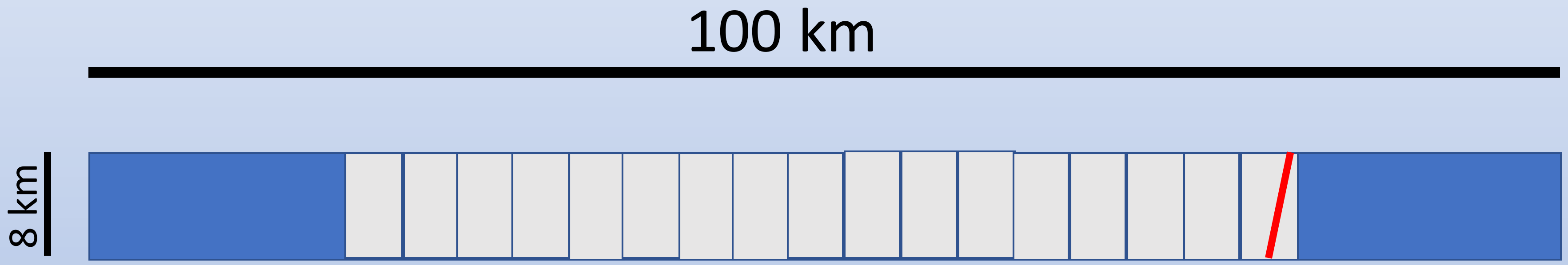

Residual ground speed = .045 m/s

More on CPEX 2017 tomorrow by Shuyi Chen

# Example ground return calibrations with residual ground speed

| Date | Yaw Correction | Pitch Correction | Ground Speed(m/s) | GSF |
|---|---|---|---|---|
| | | | | |
| May 27 | -0.30 | -0.30 | 0.037 | -0.059 |
| May 29 | -0.30 | -0.30 | 0.199 | 0.025 |
| June 1 | -0.35 | -0.30 | 0.045 | -0.007 |
| June 15 | -0.45 | -0.20 | 0.037 | 0.038 |
| June 23 | +0.05 | -0.60 | 0.023 | -0.018 |
| June 24 | -0.15 | -0.55 | 0.101 | 0.037 |

# DAWN vs dropsonde sampling comparisons



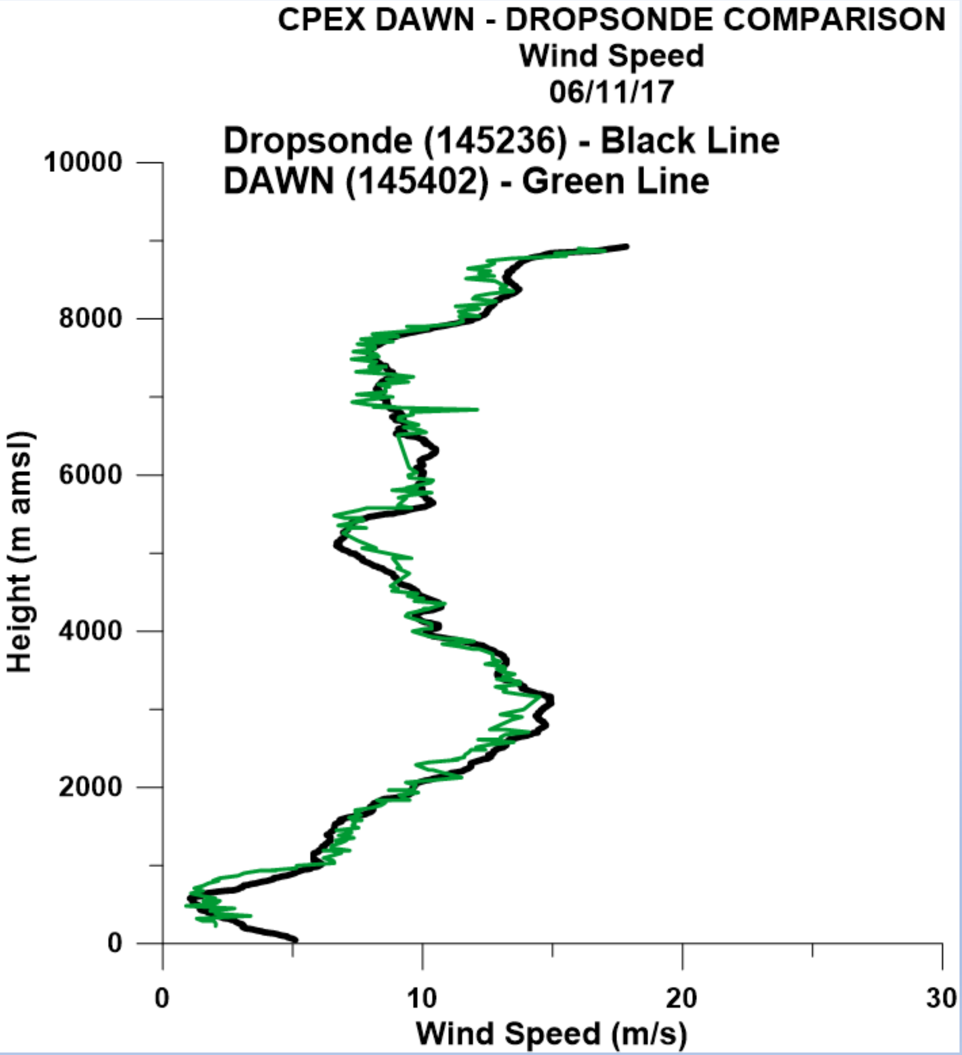

Dropsonde: 30 -20m/s fall speeds
Time in flight: 8000 m in ~5.3 minutes
DC-8 ground distance: ~ 65 km
Horizontal drift (10m/s wind): 3.2 km

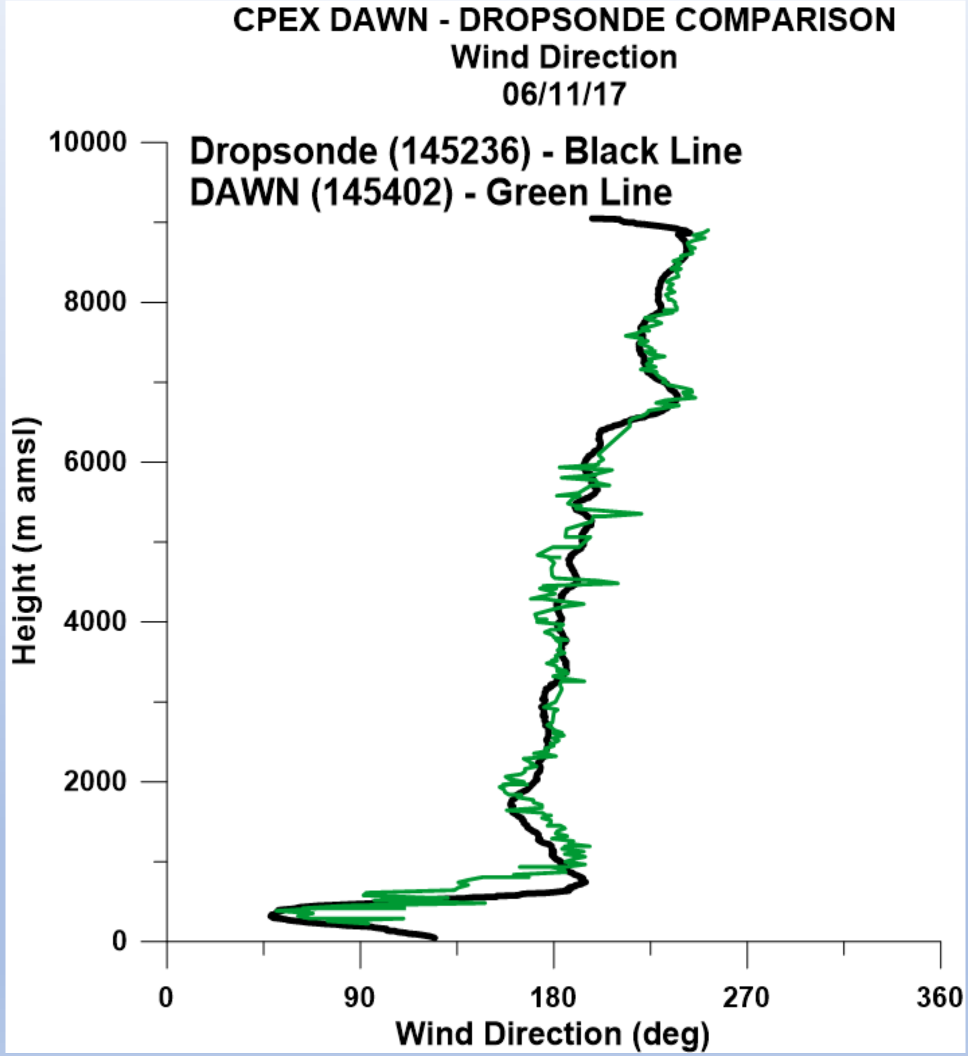
DAWN: ~10 seconds sampling +9 seconds overhead per sounding (3.8km)

## 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)

| | Number 37m seg | MEAN Z DIFF (m) | BIAS (m/s) | MEAN ABS (ΔWS) | ΔWS RMSD |
|---|---|---|---|---|---|
| ALL | 15517 | 3.08 | 0.09 | 1.13 | 1.55 |
| 2 LOOK | 6921 | 3.26 | 0.05 | 1.28 | 1.72 |
| 5 LOOK | 8596 | 2.93 | 0.13 | 1.01 | 1.39 |

# DAWN-Dropsonde comparisons from CPEX 2017 Wind Direction (degrees)

| | Number 37m seg | MEAN Z DIFF (m) | BIAS (deg) | MEAN ABS (ΔWD) | ΔWD RMSD |
|---|---|---|---|---|---|
| ALL | 15517 | 3.08 | 0.62 | 11.19 | 20.69 |
| 2 LOOK | 6921 | 3.26 | 0.68 | 12.66 | 24.10 |
| 5 LOOK | 8596 | 2.93 | 0.56 | 10.01 | 17.44 |

# Differences by wind speed interval (m/s)

| Wind Speed Interval | Number 37m seg | MEAN Z DIFF (m) | BIAS (m/s) | MEAN ABS(ΔWS) | ΔWS RMSD |
|---|---|---|---|---|---|
| 0-5 m/s | 3193 | 3.05 | -0.36 | 1.00 | 1.38 |
| 5-10 m/s | 5999 | 3.00 | 0.10 | 1.11 | 1.47 |
| 10-15 m/s | 3717 | 3.09 | 0.27 | 1.17 | 1.57 |
| >15 m/s | 2608 | 3.26 | 0.40 | 1.26 | 1.83 |

| Wind Speed Interval | Number 37m seg | MEAN Z DIFF (m) | BIAS (deg) | MEAN ABS(ΔWD) | ΔWD RMSD |
|---|---|---|---|---|---|
| 0-5 m/s | 3193 | 3.05 | 4.34 | 23.40 | 37.4 |
| 5-10 m/s | 5999 | 3.00 | 0.43 | 10.08 | 16.1 |
| 10-15 m/s | 3717 | 3.09 | -0.99 | 6.48 | 9.30 |
| >15 m/s | 2608 | 3.26 | -1.22 | 5.48 | 10.13 |

# Differences by height interval (km)

| Height Interval | Number 37m seg | MEAN Z DIFF (m) | BIAS (m/s) | MEAN ABS(ΔWS) | ΔWS RMSD |
|---|---|---|---|---|---|
| 0-3 km | 4935 | 2.52 | -0.02 | 0.95 | 1.26 |
| 3-6 km | 2079 | 2.91 | 0.26 | 1.20 | 1.62 |
| 6-9 km | 5774 | 3.32 | 0.27 | 1.14 | 1.58 |
| 9-12 km | 2732 | 3.70 | -0.20 | 1.38 | 1.84 |

| Height Interval | Number 37m seg | MEAN Z DIFF (m) | BIAS (deg) | MEAN ABS(ΔWD) | ΔWD RMSD |
|---|---|---|---|---|---|
| 0-3 km | 4935 | 2.52 | 1.62 | 9.79 | 17.5 |
| 3-6 km | 2079 | 2.91 | 0.78 | 10.10 | 18.4 |
| 6-9 km | 5774 | 3.32 | 0.31 | 14.25 | 26.4 |
| 9-12 km | 2732 | 3.70 | -0.68 | 8.09 | 11.88 |

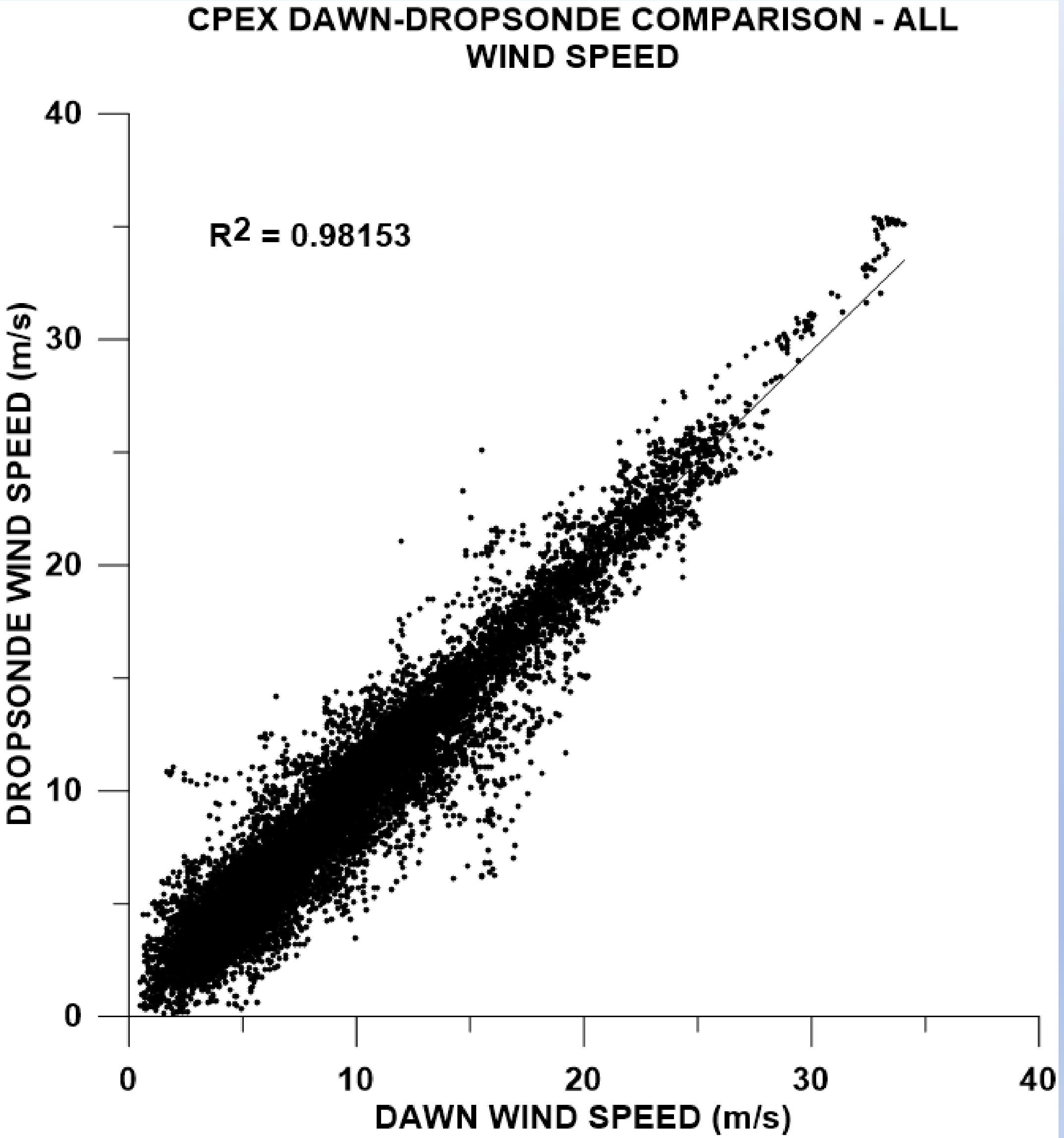
# Difference sorted by convective conditions

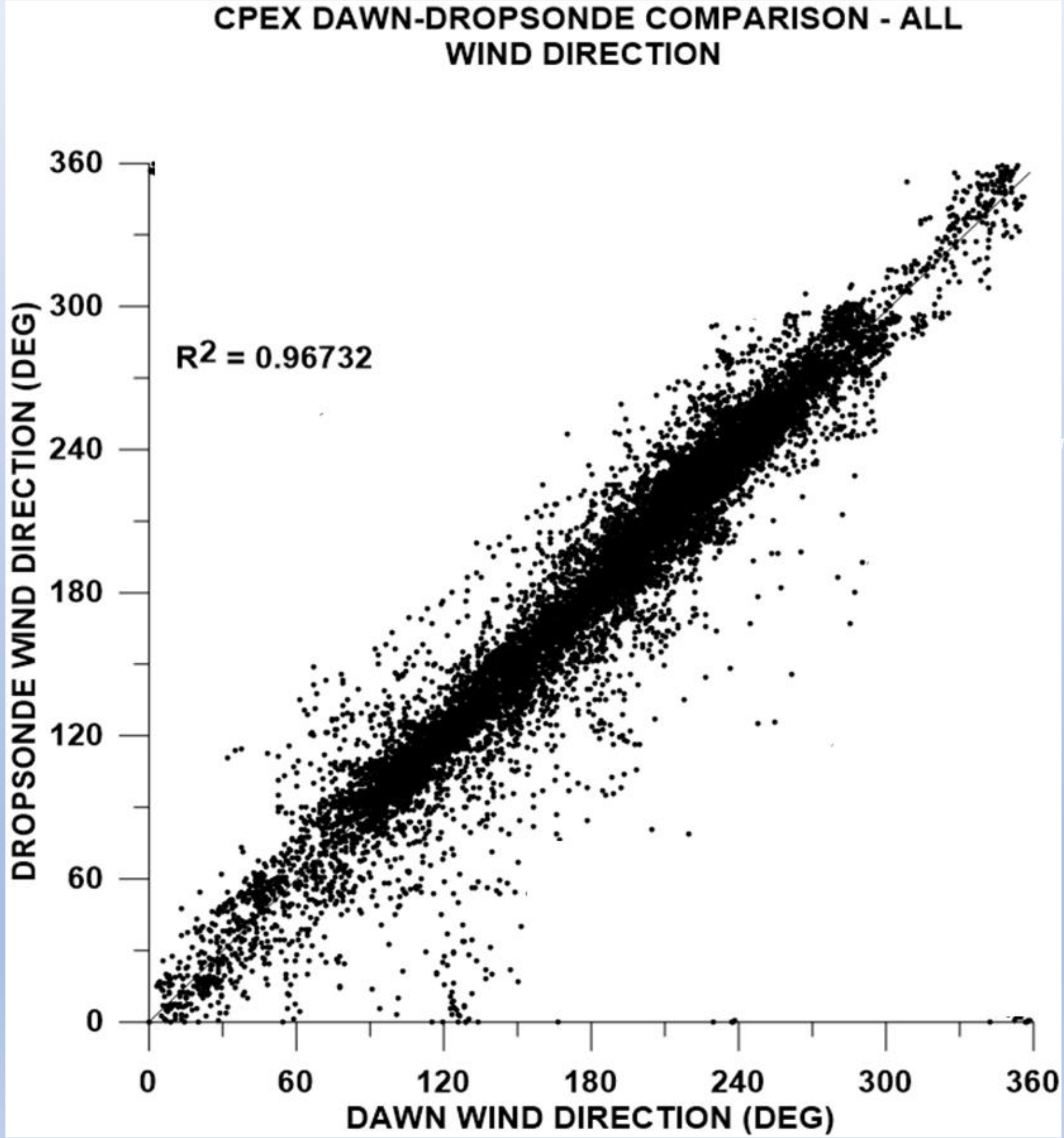
| Day | Environment | Number 37m segments | MEAN Z DIFF | BIAS (m/s) | MEAN ABS (ΔWS) | RMSD (m/s) |
|---|---|---|---|---|---|---|
| May 27 | GoM Undisturbed | 1351(9) | 2.77 | -.039 | 0.66 | .834 |
| May 29 | W Car. Sea Scatt. Convec | 1467(13) | 2.86 | .17 | 1.04 | 1.35 |
| May 31 | E of Bahamas Scatt. Convec | 1637(13) | 2.83 | 0.18 | 0.93 | 1.21 |
| June 1 | Eastern GoM Org. Convec | 590 (13) | 3.31 | -0.08 | 1.60 | 2.12 |
| June 2 | GoM Convective | 1415 (17) | 3.38 | 0.23 | 1.24 | 1.64 |
| June 6 | Eastern GoM Undisturbed(W) Convec (E) | 893 (6) | 3.04 | 0.18 | 0.97 | 1.24 |
| June 10 | E of Bahamas Org. Convec | 1239 (14) | 3.11 | 0.31 | 1.26 | 1.67 |
| June 11 | Central GoM Org. Convec/ Inflow | 1550 (13) | 2.99 | -0.01 | 1.22 | 1.81 |
| June 15 | Caribbean Sea Convective | 295 (4) | 3.77 | 0.93 | 1.78 | 2.09 |
| June 16 | W Car. Sea Convective | 991 (12) | 3.25 | -0.07 | 1.40 | 1.95 |
| June 19 | GoM Convective/ Pre TS Cindy | 513 (8) | 3.86 | -0.45 | 1.20 | 1.60 |
| June 20 | Central GoM Convective/ TS Cindy Inflow | 1454 (12) | 3.30 | 0.04 | 1.18 | 1.62 |
| June 21 | Northern GoM Convective/ TS Cindy | 1604 (22) | 3.00 | 0.40 | 1.16 | 1.54 |
| June 23 | E of Bahamas Undisturbed | 518 (6) | 2.58 | 0.02 | 0.89 | 1.17 |

# DAWN_DROP COMPARISON TABLE CPEX (162 DROPS) – WIND DIRECTION

| Day | Environment | Number 37m segments | MEAN Z DIFF | BIAS (deg) | MEAN ABS (ΔWD) | RMSD (deg) |
|---|---|---|---|---|---|---|
| May 27 | GoM Undisturbed | 1351 (9) | 2.77 | 3.57 | 10.27 | 18.0 |
| May 29 | W Car. Sea Scatt. Convec | 1467 (13) | 2.86 | 2.68 | 10.37 | 18.63 |
| May 31 | E of Bahamas Scatt. Convec | 1637 (13) | 2.83 | 0.57 | 15.16 | 29.80 |
| June 1 | Eastern GoM Org. Convec | 590 (13) | 3.31 | 0.43 | 6.92 | 8.41 |
| June 2 | GoM Convective | 1415 (17) | 3.38 | -2.02 | 6.88 | 10.25 |
| June 6 | Eastern GoM Undisturbed(W) Convec (E) | 893 (6) | 3.04 | -2.59 | 6.14 | 7.51 |
| June 10 | E of Bahamas Org. Convec | 1239 (14) | 3.11 | 1.03 | 16.50 | 24.0 |
| June 11 | Central GoM Org. Convec/ Inflow | 1550 (13) | 2.99 | 0.48 | 8.89 | 12.69 |
| June 15 | Caribbean Sea Convective | 295 (4) | 3.77 | -4.30 | 11.42 | 15.76 |
| June 16 | W Car. Sea Convective | 991 (12) | 3.25 | -0.17 | 24.56 | 40.01 |
| June 19 | GoM Convective/ Pre TS Cindy | 513 (8) | 3.86 | -2.84 | 8.71 | 12.39 |
| June 20 | Central GoM Convective/ TS Cindy Inflow | 1454 (12) | 3.30 | 0.28 | 8.94 | 19.05 |
| June 21 | Northern GoM Convective/ TS Cindy | 1604 (22) | 3.00 | 2.23 | 8.26 | 13.12 |
| June 23 | E of Bahamas Undisturbed | 518 (6) | 2.58 | 3.20 | 15.1 | 30.7 |

# All DAWN – Dropsonde Comparisons from 2017 CPEX
# (162 ~ co-located, coincident DAWN and Dropsonde Profiles)



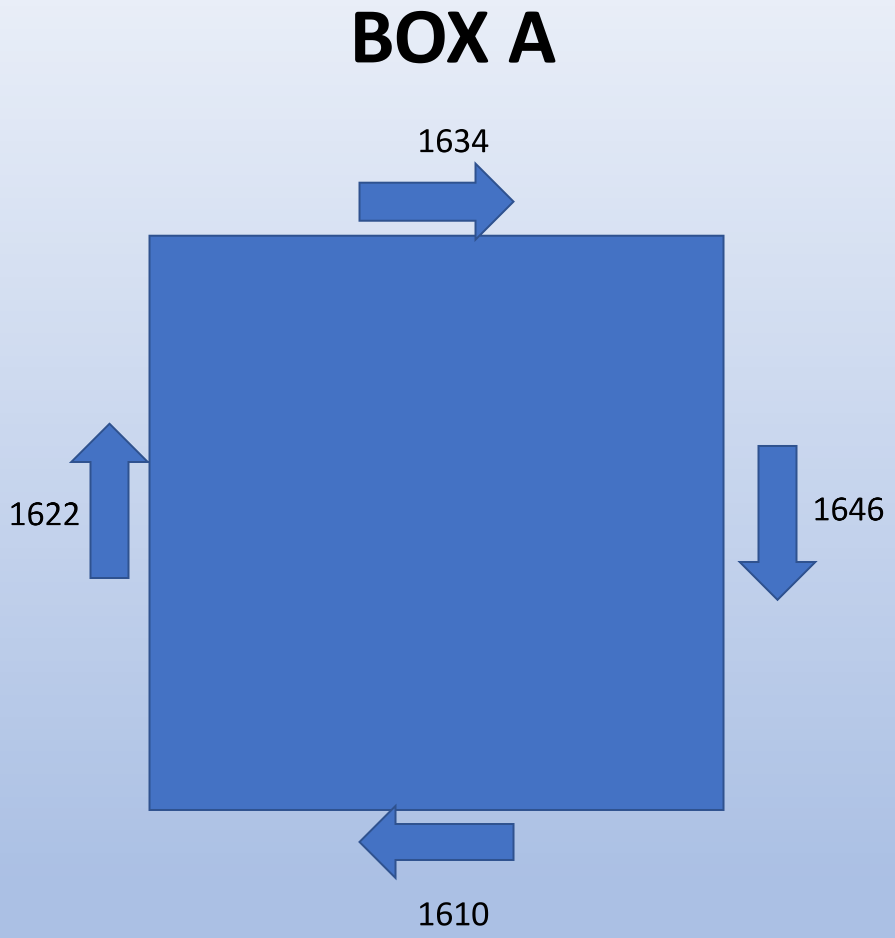



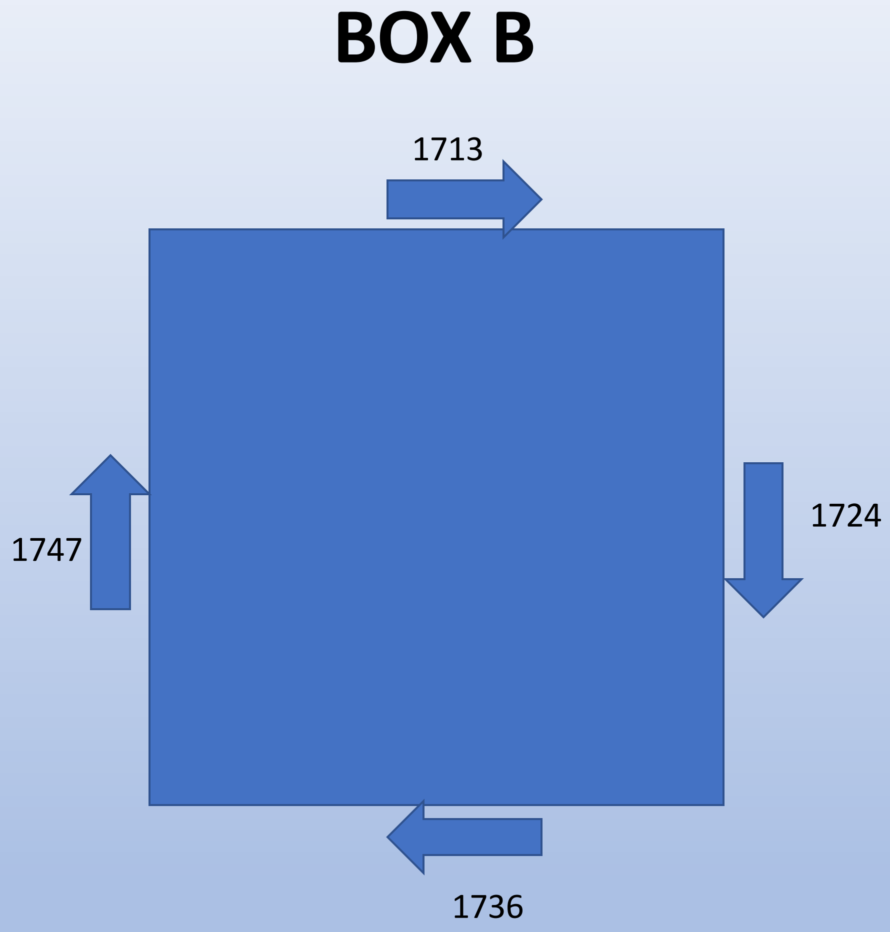
# DAWN's performance supports CPEX science

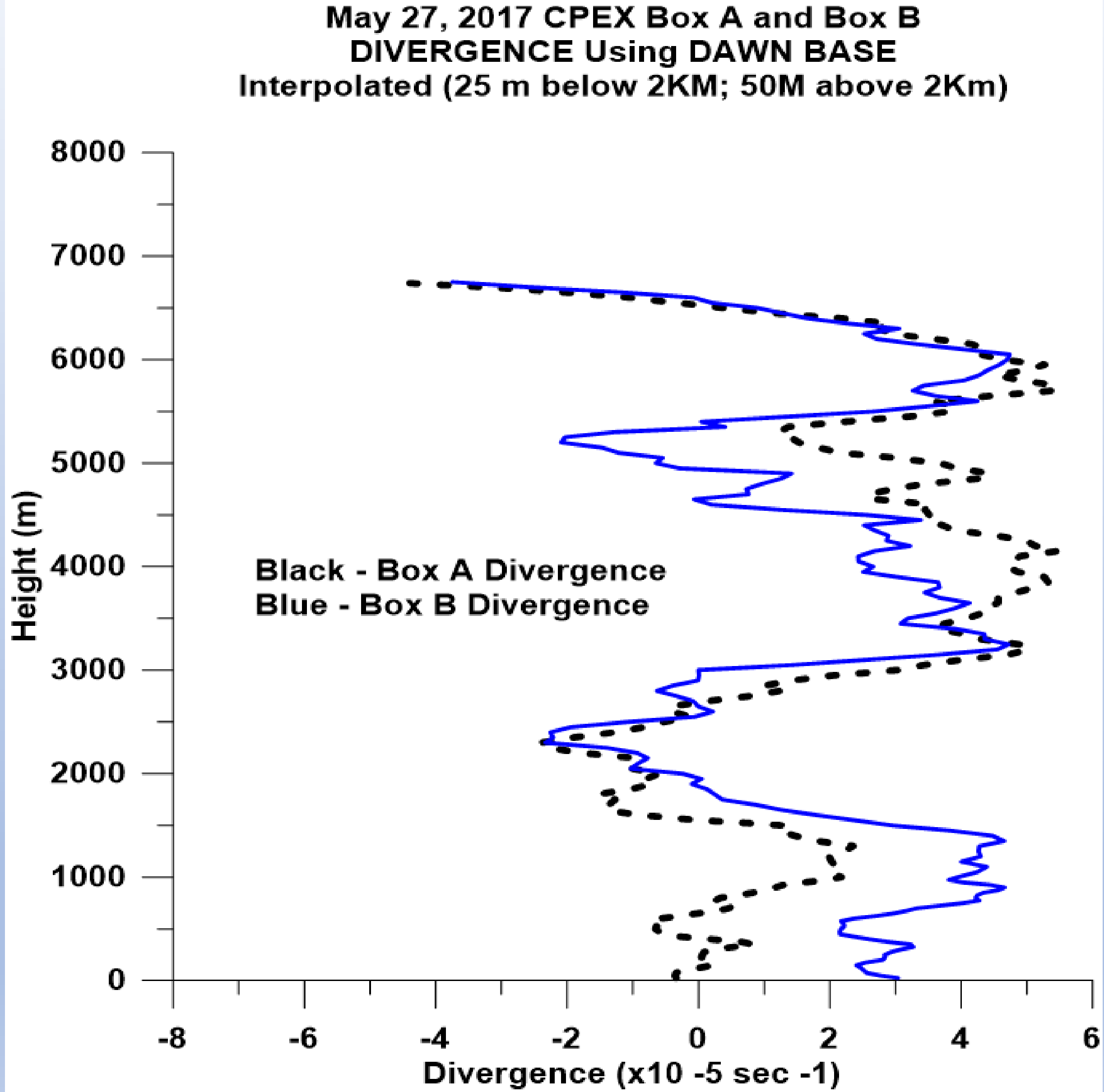
- Divergence computations within 100km x 100km x 10km volumes containing cloud amounts ranging from no cloud through deep convection
- Single shot investigations of PBL dynamics
- Other examples of science investigations will be presented tomorrow by Shuyi Chen.

CPEX Box for divergence and vorticity calculations for various classes of convection

**No cloud situation**


BOX A
1634
1622
1646
1610


BOX B
1713
1747
1724
1736

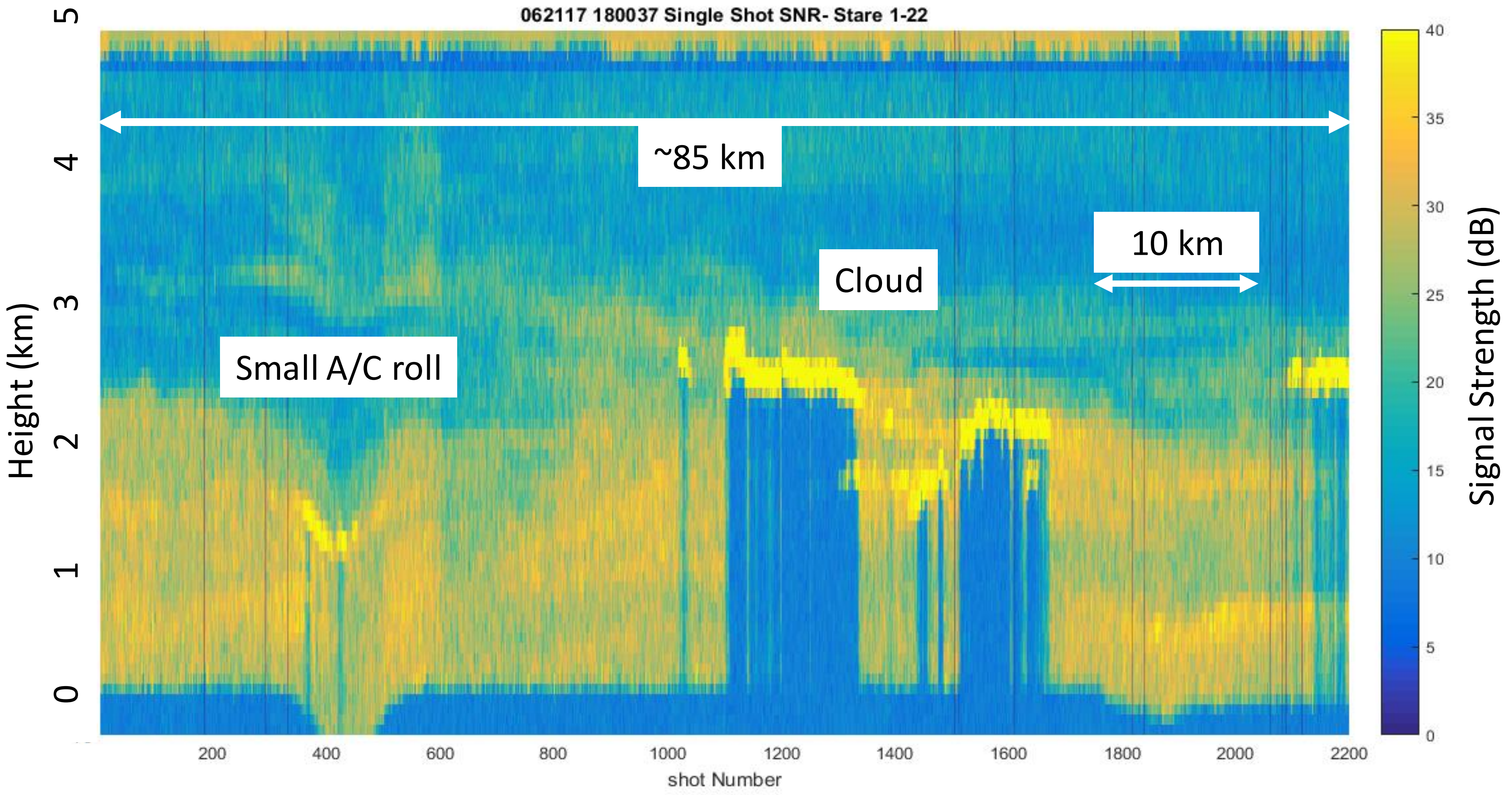



Example of divergence within a CPEX Box of dimensions 100km x 100km x 7km.

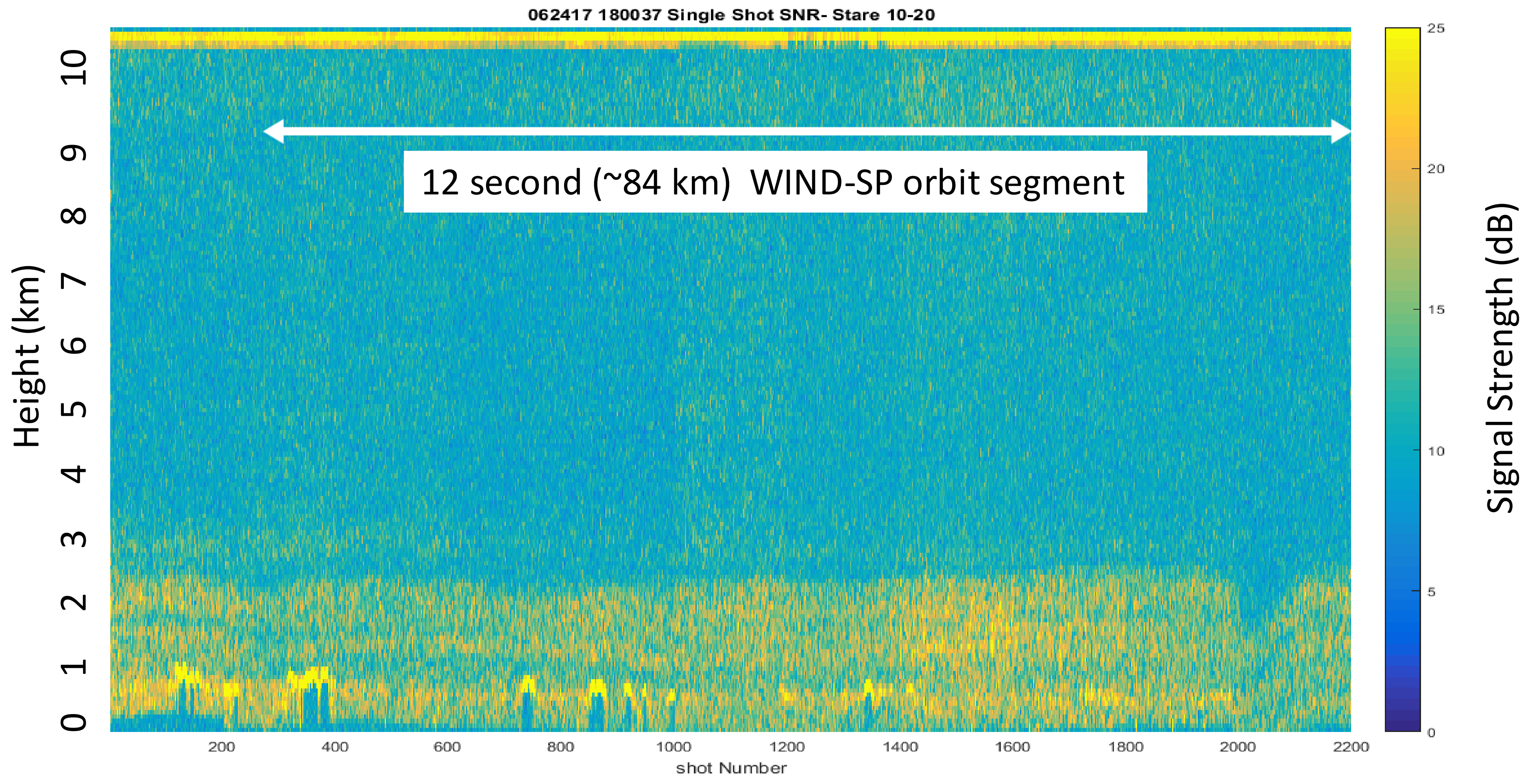
Between 20 and 24 DAWN soundings along each side of the box.

The time interval between Box A and Box B is ~ 80 minutes

# Example of Single Shot Returns from DAWN during CPEX (~20m between shots; ~60m vertical resolution)



# Example of DAWN's mapping the ABL from 10km FL



# Summary

- DAWN ‘s performance during CPEX 2017 demonstrated
  - Frequent complete to near complete wind profiles from flight levels ~10km to the surface
    - Although only the basic high resolution (75 meter processing with 37m sliding gates) DAWN data was used in the dropsonde comparisons, advanced signal processing such as adaptive integration and supervised search have greatly improved vertical coverage.
  - By inspection and filtering, most of the difference between DAWN and dropsondes is attributable to sampling different volumes at different times, not measurement error.
- Bias is most critical for Aeolus Cal/Val
  - Based upon computed ground returns (after calibration), the residual ground speed is computed to < .20 m/s (~ .10 m/s LOS)
  - Based upon more than 15000 comparisons from 162 dropsondes, DAWN has ~.15 m/s bias in wind speed and ~.7 degrees bias in direction.